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RELATING TO THE PRODUCTS, PROCESSES AND INVESTIGATIONS OF
THE PHILIPS INDUSTRIES

DISPENSER CATHODES

I. INTRODUCTION
II. THE PRESSED CATHODE
III. THE IMPREGNATED CATHODE

Since its introduction in 1949, the L cathode has been adopted for many types of electronic tubes, including television camera tubes, disc triodes, klystrons and magnetrons. In the later development two new variants of the L cathode have been evolved which differ considerably in their construction from the original form and which will perhaps contribute towards a marked extension of the field of application for this type of cathode.

I. INTRODUCTION

by A. VENEMA.

621.385.032.213.13

The L cathode, a thermionic electron emitter, which was developed in the Philips Research Laboratories at Eindhoven, was described in this journal some years ago 1). It possesses a number of highly attractive properties. Many details on the L cathode can be found in the article cited, but a few of its properties will be discussed here which have a special bearing on the development of two new types of cathodes to be dealt with in the subsequent articles by Hughes and Coppola and by Levi.

Investigations conducted by Rittner, Rutledge and Ahlert 2) in the Philips Laboratories in Irvington (U.S.A.) have led to a clearer insight into the mechanism of the function of the L cathode. These investigations will receive attention in a later issue of this journal.

The L cathode has an emitting surface consisting of porous tungsten. The porous tungsten body forms one wall of a chamber whose other walls consist of non-porous (fully sintered and worked) molybdenum. During manufacture a tablet comprising a solid solution of barium and strontium carbonates is introduced into the chamber. The cathode is mounted in the valve and is then heated on the pump system whereupon the carbonates decompose and mixed crystals of barium-strontium-oxide are formed. The carbon dioxide liberated in the decomposition leaves the cathode through the porous tungsten body and is pumped off. The cathode at this stage does not yet possess good emitting characteristics. These are obtained by means of a special activation process, which begins as soon as carbon-dioxide evolution ceases, and which is carried out at a temperature of about 1250 °C. The electron emission from the porous tungsten surface, which is initially slight, shows a roughly uniform increase during the process. Usually the process is interrupted at a given moment so that the valve can be taken off the pump system. At this stage the emission has not yet reached its end value, but the rate of increase has become relatively slow. Activation is continued on a test rack until the emission has become constant. The cathode is then ready for use.

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1) H. J. Lemmens, M. J. Jansen and R. Loosjes, Philips tech. Rev. **11**, 341, 1949/50.

2) E. S. Rittner, R. H. Ahlert and W. C. Rutledge, J. appl. Phys. **28**, 156, 1957 (No. 2).
W. C. Rutledge and F. . Rittner, J. appl. Phys. **28**, 167, 1957 (No. 2).

During the decomposition of the carbonates the tungsten is at a temperature of about 1100 °C. The oxydation by the liberated carbon dioxide to which the tungsten is subject at this temperature has been found to have an adverse effect on the duration of the activation process. Impurities which may be present on other parts and on the wall of the tube, likewise can considerably increase this duration.

The emission properties of a cathode are characterized by the two parameters A and φ_0 in Richardson's formula, which reads:

$$j_s = AT^2\,\mathrm{e}^{-\frac{e\varphi_0}{kT}}\,; \qquad A = A_0\,\mathrm{e}^{-\frac{e}{k}\frac{\Delta\varphi}{\Delta T}}\,,$$

where

j_s = saturation current density in A/cm^2,
A_0 = emission constant in (A/cm^2) degree^{-2},
T = absolute temperature in °K,
e = charge on the electron in coulombs,
φ_0 = work function in volts extrapolated to 0 °K,
k = Boltzmann constant in watt sec/degree.

The emission constant A_0 is given by the expression

$$A_0 = G\bar{D}\frac{2\pi\, m\, e\, k^2}{h^3}\,,$$

in which

G = occupation number (in most cases 2),
$\bar{D}$ = mean electron transmission coefficient of the potential barrier at the emitter surface,
m = mass of the electron in grams,
h = Planck's constant in watt sec^2.

For the L cathode, $A \approx 2.5$ (A/cm^2) degree^{-2} and $\varphi_0 = 1.67$ V [2]). (This means that such a cathode will have a zero-field saturation current density of 4.7 A/cm^2 at a temperature of 1400 °K.) For tungsten $\varphi_0 = 4.54$ V.

The reduction in the work function is explained by the adsorption of barium and oxygen atoms on the tungsten surface. The barium atoms are produced through reduction of the barium oxide, vaporized in the chamber, by the tungsten and make their way to the cathode surface through the porous tungsten body. The special properties of the L cathode are connected with the *metallic* nature of the emitting surface and with the *dispensation* of barium from the chamber (hence the name: dispenser cathode); the dispensation process continues until all the available barium oxide has been reduced.

Among the variable characteristics of the L cathode may be listed:

1) High emission, even in continuous operation.
2) Mechanical robustness, as the tungsten surface is particularly strong.
3) The emitting surface can be rendered very flat and smooth.
4) A negligible potential drop across the cathode.
5) Long life amounting to several thousand hours, even when there is a relatively high pressure of residual gas in the tube.
6) Recoverability from poisoning.
7) Capability of withstanding strong ionic bombardment.

The first four properties derive from the metallic nature of the cathode. The current delivered by the cathode produces only a small amount of heat in the tungsten body itself, since the latter has little electrical resistance. In this respect it differs greatly from semiconductor cathodes, such as the oxide cathode. With the latter the heat generated in the cathode itself is so great at high emission current density as to cause serious damage.

The properties 5) and 6) result from the continuous dispensation of barium. Should the cathode be poisoned, it is found to recover in a period lasting from a few seconds to a few minutes, the time depending upon the temperature.

The seventh property is connected both with the metallic nature of the cathode and with the barium dispensation.

Some limitations of the L cathode, however, should not pass unmentioned:

1) The time spent on the pumping system and the activation time are fairly long. Mention has already been made of the oxidation of the porous tungsten and the effect of this oxidation on the activation time. In order to keep the oxidation within reasonable limits, the decomposition of the carbonates must occur at relatively low temperatures, which makes it a relatively slow process. Since very slow decomposition would demand far too much time, a compromise must be found.
2) A good seal between the porous tungsten body and the molybdenum is essential. If the joint were to allow barium to escape through it, instead of through the pores in the tungsten, excessive evaporation and a shorter life would result and under unfavourable conditions the emission might be affected. A perfectly tight joint can be made with resistance or arc welding. This welding operation, however, which must be carried out in a controlled atmosphere, is not very well suited to mass production.
3) The dimensions in which the L cathode can be made are subject to certain limits. It will be clear at once that the chamber construction may make for difficulties where the cathode has to be very small. On the other hand with very large cathodes, trouble may arise in the temperature

distribution over the surface, since a large part of the heat is supplied via the weld connecting the tungsten and molybdenum. The temperature is lower at a somewhat greater distance from the weld than in its immediate vicinity.

These limitations motivated an investigation which was carried out in the Philips Laboratories in Irvington. The investigation resulted in the development of two new types of cathodes in which the advantages of the L cathode were retained while its limitations were overcome. These new types, the *pressed cathode*[3]) and the *impregnated cathode*[4]) [5]) [6]), work on the same principles as the L cathode. The emitting surface is of tungsten, or a tungsten-molybdenum alloy, the work function of which has been lowered by adsorption of barium and oxygen atoms. The new cathodes differ from the L cathode in that the barium generating compound is not contained in a separate chamber but is taken up in the cavities of the porous metal body. The barium generating compound used in both cathodes produces much smaller quantities of undesirable gas than that in the L cathode. Moreover, a gas-tight weld is no longer necessary and more leeway is obtained in choosing the shape and dimensions of the cathodes.

In anticipation of the descriptions of the pressed and impregnated cathodes that are given below, it may be remarked that the emission properties of the three types are broadly the same. Two notable differences concern the method of manufacture of the various cathodes and the rate of barium dispensation. In the pressed cathode, for example, this rate of dispensation is greater than in the other types. Consequently this cathode shows a greater rate of evaporation.

The pressed cathode was principally developed as a flat cathode, the objective being to arrive at a product that would lend itself to mass production. The impregnated types can be made in any desired shape, e.g. as flat or cylindrical cathodes. The possibilities in shaping and dimensioning the latter type of cathode are very large indeed. The construction of this cathode was not primarily intended for, but does not preclude it from mass production. With mass production in mind, it is difficult at this stage to express a preference for either the one or the other cathode, since there are other properties that cannot be ignored in the assessment. Apart from the problem of barium dispensation, the problem of the insulation of the emitting body from the filament which serves to heat the cathode should be mentioned here. In its original version the impregnated cathode suffered from cathode-to-heater emission, but this difficulty has been overcome for most types of planar cathodes in a new design which is described in Part III.

When a given tube has to be fitted with a dispenser type cathode, the properties mentioned, and perhaps others besides, will determine which of the three types should be used: L cathode, pressed cathode or impregnated cathode. The choice can be expected to differ for different applications.

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[3]) P. P. Coppola and R. C. Hughes, Proc. Inst. Radio Engrs. **44**, 351, 1956 (No. 3).

[4]) R. Levi, J. appl. Phys. **24**, 233, 1953.

[5]) R. Levi, Le Vide **9**, No. 54, 284, 1954.

[6]) R. Levi, J. appl. Phys. **26**, 639, 1955.

II. THE PRESSED CATHODE

by R. C. HUGHES *) and P. P. COPPOLA **).

621.385.032.213.13

The electron-emitting part of the pressed cathode consists of a body which is pressed from a powdered mixture of a tungsten-molybdenum alloy and barium calcium aluminate. The latter compound is the cathode's barium source from which barium is generated as a result of reduction by the tungsten. After pressing there follows a short heat treatment above the melting point of the aluminate which is especially important to remove injurious gases still present in the pressed mass. In what follows the chemical background underlying the choice of the components will be discussed, the manufacture of the pressed cathode will be outlined, and in conclusion, its emission characteristics will be described.

Chemical considerations on the choice of the barium source and metal

From what was mentioned in the introduction it is clear that barium-strontium carbonate is not ideal as the starting material for the barium source in the

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L cathode. A pressed mixture of barium carbonate and tungsten does not yield any barium at all on heating and thus is not suitable for a cathode. The reaction in this case (which occurs at an appreciable rate even at 600 °C) is described by the equation ¹):

$$3\,\mathrm{BaCO_3} + \mathrm{W} \rightarrow \mathrm{Ba_3WO_6} + 3\,\mathrm{CO}.$$

A pressed mixture of barium oxide and tungsten powder, on the other hand, generates barium in sufficient quantity at temperatures above 1000 °C. The reaction, which is responsible also for the barium dispensation in the L cathode, proceeds according to the equation:

$$6\,\mathrm{BaO} + \mathrm{W} \rightarrow \mathrm{Ba_3WO_6} + 3\,\mathrm{Ba}.$$

Using these substances, therefore, a cathode can be made which works on the same principle as the L cathode ²). The electrons are derived from the tungsten whose work function has been lowered by the adsorption of a monatomic layer of oxygen and barium. There are, however, two great drawbacks associated with a cathode pressed from barium oxide and tungsten ²):

1) The barium oxide in the cathode very readily reacts with water vapor and carbon dioxide in the air, so that assembly of the tube would have to be performed under such conditions that these gases cannot come into contact with the cathode. In practice this constitutes a serious difficulty.
2) The rate of the reaction between oxide and tungsten is inadmissibly high at the temperature desired for electron emission, which lies between 1000 °C and about 1250 °C. In consequence, the amount of barium formed per unit of time is far too great and cathodes of this construction display very rapid evaporation and have a short life.

A lower reaction rate could be obtained by substituting molybdenum for part of the tungsten (see below), but this would not solve the problem of rapid deterioration in air. Apart from the difficulties in the assembly the same difficulties with regard to reactivity with water vapor and carbon dioxide would be encountered, of course, in the manufacture of the cathodes.

A compound which is to dispense barium in combination with a suitable metal must meet the following requirements:

1) It must give off as little gas as possible. The desired temperature can then be speedily reached on the pumping system.
2) No oxygen must be present that could take part in the reaction other than the oxygen in the barium oxide.
3) High stability in air. The compound must not take up water vapor and carbon dioxide.
4) Its reactivity and rate of evaporation must be low compared with barium oxide.

The products obtained in reactions between barium oxide and other oxides, such as aluminum oxide, silicon dioxide and boron oxide, were found to come up more or less to the above requirements ²). The most suitable was found to be the composition: 5 moles of barium oxide and 2 moles of aluminum oxide. In view of the obvious additional requirement that the pressed cathode should have as high an electron emission as possible, it has been found desirable to add an amount of calcium oxide. It was R. Levi who first showed calcium oxide to be beneficial in the impregnated cathode (see I, ⁶)). The way in which calcium oxide exerts this beneficial influences is not yet clear; nor is it completely known as yet how the calcium oxide modifies the properties of the barium aluminate in regard to the four above-listed requirements. Discussion of the properties in relation to these requirements will therefore be confined to the composition with 5 moles of barium oxide and 2 moles of aluminum oxide.

This formulation is an approximately eutectic mixture of the compounds $\mathrm{Ba_3Al_2O_6}$ and $\mathrm{BaAl_2O_4}$ ³). Only the former adequately reacts with tungsten with generation of barium. The second compound is useful in that it increases the stability of the mixture in air and lowers the melting point. In fact, melting of the aluminate during preparation is found to be essential for satisfactory operation of the cathode. This results in the removal of most of the residual gas: accordingly, the amount of undesirable gas released later on the pump system is very small.

During operation of the cathode the tribarium aluminate may be viewed as supplying BaO by dissociation:

$$\mathrm{Ba_3Al_2O_6} \rightleftarrows 2\,\mathrm{BaO} + \mathrm{BaAl_2O_4}.$$

The barium oxide reacts further with the tungsten. The monobarium aluminate formed has no further function. Thus, no oxygen other than that in the barium oxide reacts with the tungsten, as stipulated by the second requirement.

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¹) R. C. Hughes, P. P. Coppola and H. T. Evans, J. appl. Phys. **23**, 635, 1952.

²) R. C. Hughes and P. P. Coppola, J. appl. Phys. **23**, 1261, 1952.

³) N. A. Toropov and F. Ya. Galakhov, Doklady Akad. Nauk S.S.S.R. **82**, 69, 1952.

The degree of stability in air of the aluminate with the composition 5 moles barium oxide and 2 moles aluminum oxide can be seen from *fig. 1.* This figure shows the time dependence of the weight increase for powdered barium oxide (*I*), powdered aluminate (*II*), a fused pellet of aluminate (*III*) and a pressed cathode (*IV*) on exposure at a temperature of 20 °C to air having a relative humidity of 45%. The plot demonstrates that powdered barium aluminate is far more resistant to water and carbon dioxide in the air than is powdered barium oxide; still better are the fused aluminate pellets, which show hardly any increase in weight. Finally, with the cathode itself, where the aluminate is interspersed between the separate tungsten grains, no increase in weight can be detected even after 1000 hours.

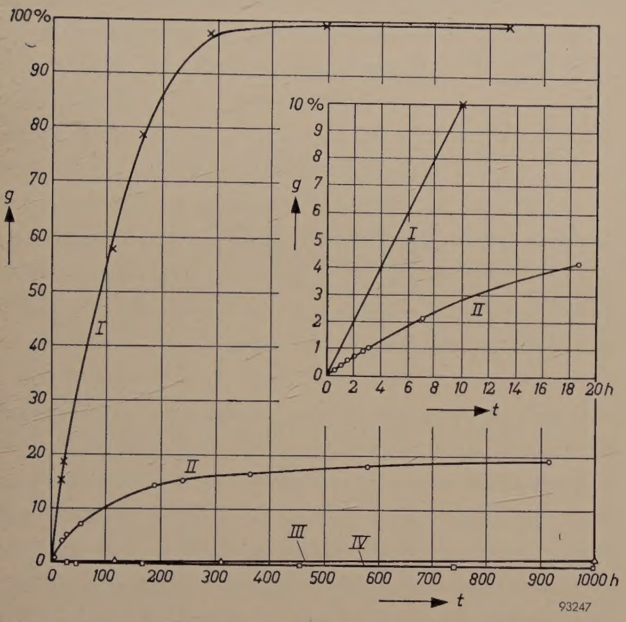

Fig. 1. The stability in air of the pressed cathode and of various emitting materials that may be used in this cathode. The percentage increase in weight *g* by uptake of water is plotted as a function of the time *t*. *I* powdered BaO, *II* powdered Ba-aluminate, *III* fused pellet of Ba-aluminate, *IV* pressed cathode.

In conclusion, there is the question of the reactivity of the barium aluminate and the evaporation of barium oxide from this aluminate. A pressed mixture of tungsten powder and aluminate powder ($5BaO : 2Al_2O_3$) is found to react on heating in a manner not quite desirable for a cathode. True, the amount of barium that escapes from the mixture per second at a temperature of 1130 °C is less than 1/100 of that given off by an equal amount (in grams) of the mixture of tungsten and barium oxide, but even at that, it is still excessive. The rate of escape of barium is determined not only by the chemical properties of the system, but also by the porosity of the tungsten matrix. This porosity is fairly large and cannot readily be further reduced by mere compression, while high-temperature sintering detracts from the properties of the cathode. The problem must therefore be resolved chemically.

Thermodynamic considerations showed that a tungsten-molybdenum alloy could be expected to give a low rate of barium production. This was confirmed by experiments. A discussion of these considerations and experiments will now be given.

The pressure of barium vapor in equilibrium with a barium compound and a reducing metal may be calculated by thermochemical methods [4][5]. The maximum rate at which barium will evaporate from this system can be determined from the equilibrium pressure. The reaction between the barium aluminate and the reducing metal can be considered to proceed in two stages:

1) the dissociation of the aluminate to form barium oxide, and
2) the reduction of the barium oxide to form barium.

Barium generation will be discussed first. The reaction involved here can be represented by the equation:

$$\mathrm{M_s + BaO_s \rightleftarrows MO_s + Ba_g},$$

where M is the reducing metal (assumed for simplicity to be bivalent); the suffixes s and g indicate whether the substance participates in the reaction in the solid or gaseous state. If only one of the reactants is gaseous, as in the above example, the equilibrium pressure can be derived from the equation:

$$\Delta G_T = -RT \ln P_{Ba} = -4.575\ T \log P_{Ba}\ .$$

Here ΔG_T is the change in free energy occurring in this reaction and is expressed in calories. R is the gas constant, and T the absolute temperature. The pressure P_{Ba} of barium is measured in atmospheres. The change in free energy can be written as:

$$\Delta G_T = \Delta H - T\Delta S.$$

For the change ΔH in enthalpy occurring in the reaction and the change ΔS in entropy a good approximation is obtained by substituting the values at room temperature, which are obtained from the tables [6].

As regards the dissociation of tribarium aluminate ($Ba_3Al_2O_6$), this will produce barium oxide and monobarium aluminate as stated above, while the monobarium aluminate ($BaAl_2O_4$) likewise may dissociate, forming barium oxide and aluminum oxide. The heat of dissociation generated in either reaction [7] is added to the heat of reaction of BaO plus metal (W or Mo) in calculating the resulting pressure of barium in equilibrium with the reaction: aluminate plus metal. The change in entropy in the dissociation of aluminate can be neglected. From the heats of dissociation of the tribarium aluminate and monobarium aluminate, the barium oxide pressure can also be calculated.

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[4] A. H. White, J. appl. Phys. **20**, 856, 1949.
[5] E. S. Rittner, Philips Res. Rep. **8**, 184, 1953.
[6] F. D. Rossini, D. D. Wagman, W. H. Evans, S. Levine and I. Jaffe, Nat. Bureau of Standards, Circular 500, 1952.

Table I. Calculated rate of evaporation of barium and barium oxide for various pressed mixtures. Temperature: 1400 °K.

System	Pressure in 10^{-6} mm Hg		Rate of evaporation in μg/cm²h		Behaviour as an electron emitter
	Ba	BaO	Ba	BaO	
W + BaO	80	6	5200	420	emits, short life
Mo + BaO	1	6	65	420	emits, moderate life
W + $Ba_3Al_2O_6$	0.5	0.14	33	10	emits, moderate life
Mo + $Ba_3Al_2O_6$	0.009	0.14	0.6	10	does not emit
W + $BaAl_2O_4$	0.0008	0.0011	0.05	0.08	does not emit
Mo + $BaAl_2O_4$	0.00002	0.0011	0.001	0.08	does not emit

The rates of evaporation of barium and barium oxide are calculated from the pressure at equilibrium using the well-known relation from the kinetic theory of gases:

$$Q = 5.83 \times 10^{-2}\, P \sqrt{\frac{M}{T}},$$

where Q represents the amount of material in grams that evaporates, calculated per cm² and per sec, P the equilibrium pressure in mm Hg, T the absolute temperature and M the molecular weight of the substance in question. Since it remains uncertain whether the equilibrium pressure will be attained in the porous substance, and since in addition the vapor may be impeded in flowing to the outside, Q will represent the largest possible quantity of material which can be obtained per sec and per cm² from the pressed cathode.

The results of the calculation for the two aluminates $BaAl_2O_4$ and $Ba_3Al_2O_6$ with the metals tungsten and molybdenum are given in *Table I*. The latter also shows the behaviour of a pressed mixture of the above substances as a cathode. It has further been assumed that the normal tungstate $BaWO_4$ or molybdate $BaMoO_4$ form. It is clear from the table that molybdenum is far less reactive than tungsten. It is likewise apparent that tungsten activated by tribarium aluminate emits, but as a cathode has only a moderate life. This is a consequence of fairly rapid evaporation as may be seen by comparing the evaporation rate with that of an L cathode at the same temperature.

From the foregoing it is to be expected that evaporation will be diminished if the tungsten is alloyed with molybdenum. *Fig. 2* shows that this is indeed the case. Here the evaporation rate is plotted for pellets pressed from different W-Mo alloys with barium aluminate of the composition $5BaO{:}2Al_2O_3$. The graph likewise gives the calculated vapor pressures for the pure molybdenum and pure tungsten mixtures.

The figure shows that the increase in evaporation observed on adding tungsten to molybdenum is proportional to the molar concentration of tungsten. In view of the calculated values of the evaporation rate listed in Table I it can be assumed that the product of evaporation in the case of pure molybdenum consists almost entirely of barium oxide, while the increase due to the tungsten consists of

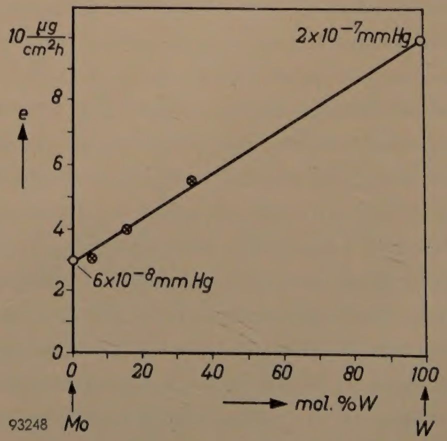

Fig. 2. The evaporation rate *e* of barium and barium oxide from pressed cathodes using a tungsten-molybdenum alloy, as a function of the tungsten content of the alloy.

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[7] The values of the dissociation heats are given by R. B. Peppler and E. S. Newman, J. Res. Nat. Bur. Standards **47**, 439, 1951.

barium. It can easily be demonstrated theoretically that the barium generation should be proportional to the tungsten content of the tungsten-molybdenum alloy (see I [3])).

The material that was eventually chosen for the pressing of cathodes consisted of 10% by weight of barium aluminate containing barium oxide and aluminum oxide in the molecular proportion of 5 to 2, and 90% by weight of a molybdenum-tungsten alloy containing 25% by weight of tungsten. This formulation gave cathodes which showed very high stability in air, contained a minimum of gas, enabled rapid activation, and combined a high emission density with long life, while at the same time the evaporation of barium and barium oxide remained within reasonable limits. The emission density was, however, appreciably smaller than that of the L cathode. As has already been mentioned, the addition of CaO increased the emission considerably, close to the L cathode value.

The manufacture of the pressed cathode

The starting materials for the preparation of the requires aluminate are barium carbonate, calcium carbonate and aluminium oxide. These are weighed out and carefully mixed in the proportions:

$$\left.\begin{array}{ll} BaCO_3 & 5\ \text{mol} \\ Al_2O_3 & 2\ \text{mol} \end{array}\right\} \quad \text{or} \quad \left\{\begin{array}{ll} CaCO_3 & 0.3\ \text{mol} \\ BaCO_3 & 5\ \ \text{mol} \\ Al_2O_3 & 2\ \ \text{mol} \end{array}\right.$$

The mixture is heated in air until it fuses. After cooling, the product is reduced to a fine powder, sieved and is kept sealed off from the air.

The metal powder is mixed very carefully with the powdered aluminate in the proportions by weight of 9 : 1 and kept sealed off from the air until the time comes for pressing. This latter operation can be performed in a number of ways, depending on the required shape of the cathode and on the manner in which it is going to be fitted in the holder. Here an inexpensive method will be described which has led to good results. The method was designed for a flat cathode having a circular emitting surface with a diameter of 3 mm. In the pressing process a fixed volume of the above-described aluminate-metal mixture is introduced into a small molybdenum cylinder. The latter is mounted in a die. The mixture is then compressed with the required pressure of 11 tons/cm² using a suitable plunger. The compact is then taken from the die, and the cathode is heated at a temperature of 1800-1900 °C in vacuo, or better in an atmosphere of hydrogen. This is a very important stage in the manufacture of the cathode. The aluminate fuses, giving off occluded gas, whereupon capillary forces effect an even distribution of the aluminate among the grains of metal.

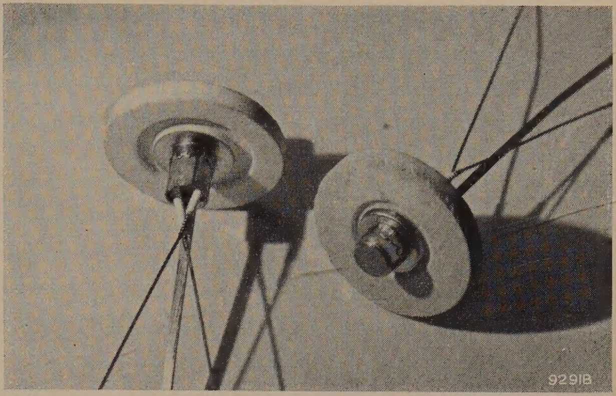

Fig. 3. Pressed cathodes with flat emitting surface (diameter 3 mm) contained in cylindrical molybdenum holders.

The molybdenum cylinder is fashioned very simply from a thin plate. This is rolled, the ends being left free. During pressing the end of the cylinder containing the powder is crimped in somewhat by the die. This will ensure a strong bonding of the pressed material to the holder after heat treatment.

The pressed surface is uniformly flat. Over the 3 mm diameter the surface was found to deviate by no more than 3 microns from a flat.

The filament for heating the cathode is fitted into the molybdenum cylinder. Cathodes of the type thus produced and intended for use in cathode-ray tubes of the grounded-cathode type are shown in *fig. 3.*

The emission characteristics

For examining the emission characteristics of these cathodes, they are mounted at a short distance from an anode in a tube. The distance between the two electrodes is made so small (a few tenths of a millimetre) that the saturation current can be drawn at a voltage of say 1000 V. The diode formed in this way is connected to a high-vacuum pump which is capable of lowering the pressure in the tube to below 10^{-6} mm Hg. The tube contains a getter to remove the gases that may be liberated after seal-off. The tube is heated for one hour in an oven at 450 °C. After cooling, the cathode is heated by applying a voltage across the heater filament, the temperature being gradually raised to 1200 °C in about 5 minutes. The anode is then degassed by high-frequency heating, and a potential of 300 V applied between cathode and anode. A current is found to flow which increases rapidly and in about 1 minute has attained a constant value. The getter is then activated and the tube is removed from the pump system by sealing the glass stem. At this point the saturation current density is already roughly half the maximum value, which is attained after the brief aging that now follows.

The saturation current cannot be measured with a constant voltage of say 1000 V, as this would lead to excessive heating of the anode. For this reason, a pulse voltage obtained from the discharge of a condenser is applied to the anode (frequency 60 per second, pulse length ~ 100 μsec). At the same time the voltage across the diode and the current passing through the diode are reproduced on an oscilloscope in a horizontal and a vertical direction respectively[8]). *Fig. 4* shows the relationship between voltage and current for various cathode temperatures (the current density rather than the current is plotted on the vertical axis). The cathode used in this experiment contained Ba-Ca-aluminate.

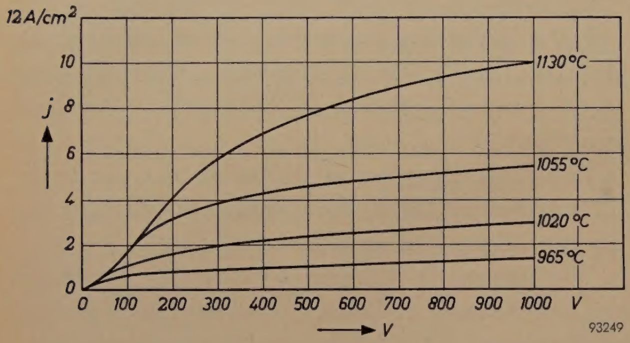

Fig. 4. Current density j of a pressed cathode (with CaO), measured in a diode and plotted as a function of the applied anode voltage V at various cathode temperatures.

As far as it has been possible to ascertain (within the limits of tube loading studied), the currents that flow through the diode for a D.C. potential are the same as those obtained with a pulse voltage as plotted in fig. 4.

In *fig. 5* the current density measured at a cathode temperature of 1020 °C and an anode voltage of 1000 V, is plotted as a function of the time in operation. The various curves relate to cathodes pressed from barium aluminate (5 BaO : 2 Al_2O_3) and various Mo-W alloys. With pure tungsten the life is too short, owing to excessive evaporation. As the molybdenum content increases, evaporation diminishes and the life is prolonged. At first the current density remains the same, but at a high molybdenum content, the emission falls, becoming negligible for 100% Mo. The alloy containing 75% by weight of molybdenum and 25% by weight of tungsten as mentioned above is about the best compromise.

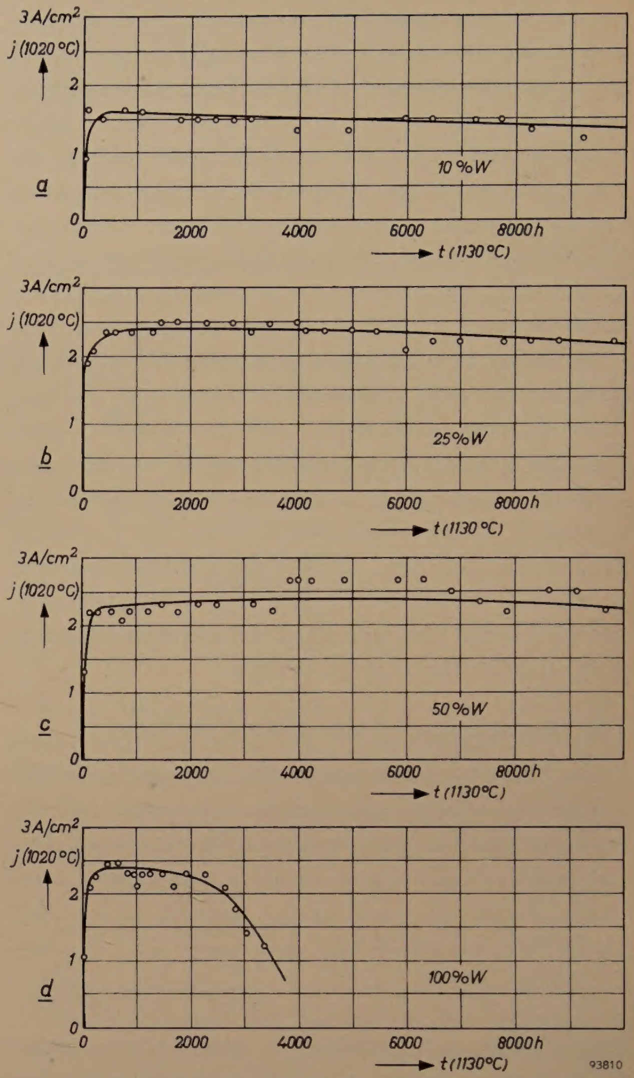

Fig. 5. Current densities j of various pressed cathodes at an anode potential of 1000 V, as a function of the operation time t.
a) Alloy of 10% W — rest Mo (by weight).
b) 25% W — rest Mo.
c) 50% W — rest Mo.
d) Pure W.
All four cathodes were made using barium aluminate (5BaO: $2Al_2O_3$). During the hours in operation, plotted along the abscissa, the cathode temperature was 1130 °C; the temperature was reduced to 1020 °C for each measurement.

The improvement in the emission found on adding calcium oxide can be seen from *fig. 6*. The temperature was 1130 °C.

Determination of the constants in Richardson's formula give the values:

$\varphi_0 = 1.7$ V and $A = 1.8$ (A/cm²) degree^{-2} for the barium aluminate, and

$\varphi_0 = 1.7$ V and $A = 2.4$ (A/cm²) degree^{-2} for the barium-calcium aluminate.

The activation process can be visualized by producing an electron-optical image of the cathode on

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[8]) R. Loosjes and H. J. Vink, Philips Res. Rep. 2, 190, 1947.

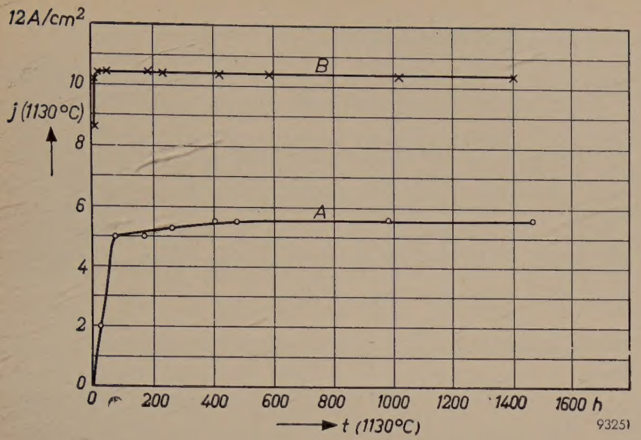
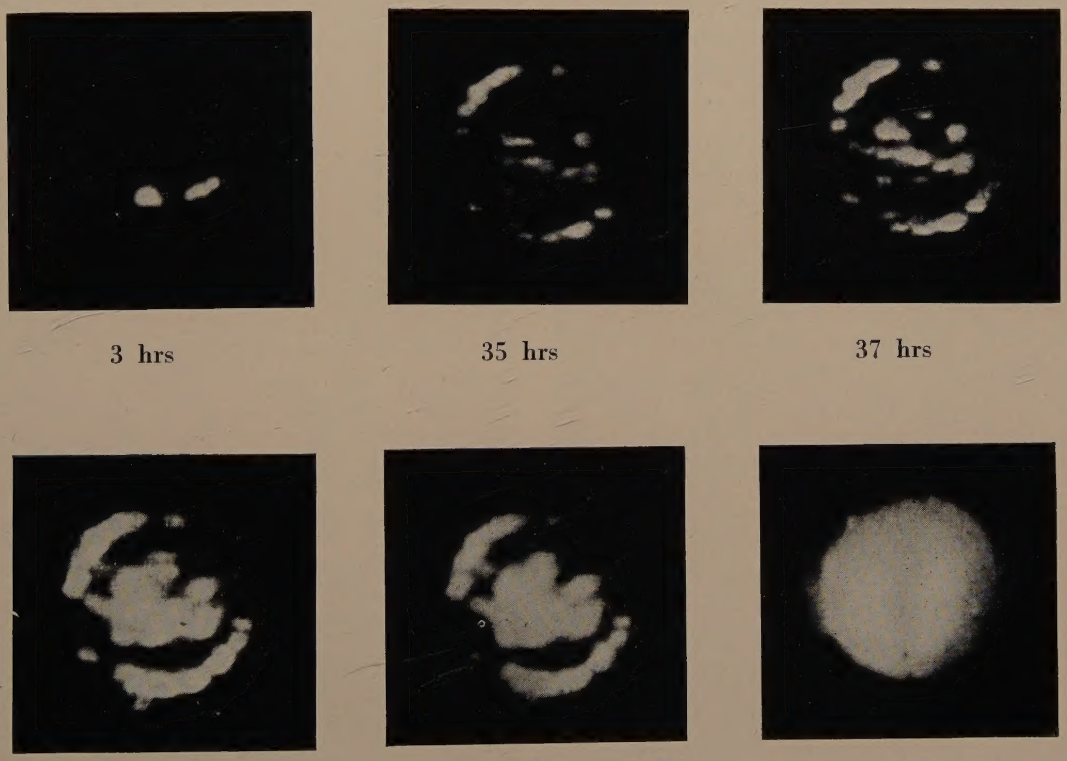


Fig. 6. Current densities of pressed cathodes at an anode voltage of 1000 V, as a function of the life. Temperature was the same during operation and measurement, namely 1130 °C. *A* barium aluminate; *B* barium-calcium aluminate.

a fluorescent screen. The result for a temperature of 950 °C is reproduced in *fig. 7*. Naturally at this temperature the activation process proceeds far more slowly than at the usual temperature of 1200 °C.

Experiments with pressed cathodes, carried out with a tube which had been exhausted on the pump to 10^{-3} mm Hg and whose pressure after sealing had been further reduced to about 10^{-6} mm Hg with the aid of a getter, showed the saturation current density to be pretty much the same as that attained under very much more favorable conditions on the pump system. It is to be expected, therefore, that pressed cathodes will lend themselves for use in tubes exhausted with two-stage rotary pumps which can get down to a pressure of 10^{-3} mm Hg and which are usual in mass production equipment.

Exposure of the activated cathode to the air will necessitate a second activation, but it has been found that this does not take more time than the first, and the current density obtained is the same as before admission of the air. This process can be repeated five times before its effect on the activation time and emission becomes appreciable.



3 hrs 35 hrs 37 hrs

40 hrs 42 hrs 58 hrs

Fig. 7. Electron-optical images of the emitting cathode on a fluorescent screen, photographed at various phases in the activation process. (The latter was performed at 950 °C and was therefore much slower than normal.) The activation time is indicated under each photograph.

III. THE IMPREGNATED CATHODE

by R. LEVI *).

621.385.032.213.13

The impregnated cathode is made by impregnating a porous tungsten body with a suitable barium compound in the molten state, this body having one or more surfaces that are to emit electrons at high temperatures. The most salient feature of this cathode is the wide variety of sizes and shapes made possible by this method of fabrication.

In an early version of the cathode, the impregnant consisted of a mixture or normal and basic barium aluminates. While this cathode displayed the desired improvements in processing and manufacture over the L cathode, the emission was significantly lower. A later version of the cathode, which forms the subject of this present article, overcame this emission difficulty by the addition of calcium oxide.

Choice of the barium source and the metal

In the L cathode the activating material, barium and barium oxide, makes its way to the emitting surface through the pores in the porous tungsten body. In so doing, this stream of atoms and molecules encounters a certain resistance which depends upon the size of the pores. This resistance will generally be greater, the smaller the pores. Thus the dispensation and also the evaporation of barium and barium oxide can be controlled within certain limits by controlling the porosity. In the pressed cathode, it was not possible to make the pores small enough to prevent excessive evaporation. The problem of reducing the barium dispensation therefore had to be approached in a different way. A solution was found, as described in Part II of this article, by using a molybdenum-tungsten alloy instead of pure tungsten. Such an artifice is not necessary for the impregnated cathode. The latter is made of tungsten which is given a porosity of only 17% by the choice of a suitable pressure and sintering temperature during fabrication from tungsten powder. In other words, the tungsten has a density of 83 % of the bulk value; the remaining volume consists of pores between the grains. (In the L cathode the porosity is usually 27%, and in the pressed cathode even as much as 40%.) The use of this low-porosity tungsten in conjunction with barium aluminate ($5BaO:2Al_2O_3$) and, better still, with the composition $5BaO.3CaO.2Al_2O_3$, has ensured a suitably limited dispensation of barium and barium oxide.

Barium aluminate was discussed in connection with the pressed cathode. What was said regarding its stability to air, slight release of gas, low reactivity and absence of excess oxygen, applies equally well when this material is used in the impregnated cathode. Addition of calcium oxide raises the emission and reduces evaporation.

Manufacture of the impregnated cathode

The aluminate is prepared in the manner described for the pressed cathode, but for the impregnated cathode, a different calcium-oxide-containing composition has been chosen. This is prepared from a mixture, comprising:

$CaCO_3$	3 moles
$BaCO_3$	5 moles
Al_2O_3	2 moles.

Actually the amount of $CaCO_3$ may vary over broad limits, the lower limit being 0.3 mole.

Usually the aluminate is prepared as pellets by melting, these being kept closed off from the air and powdered shortly before use.

The porous tungsten body, one or more surfaces of which are to act as sources of electrons, is first fashioned to the required dimensions. At the same time the surfaces, where this is necessary, are given an appropriate finish. Fashioning and finishing are easily done by means of a known technique developed by the author and described in this Review some time ago [1]). This technique consists in first filling the pores of a tungsten ingot, which has been sintered to the required density, with a suitable material, commonly copper. In this state, the tungsten can be turned, drilled, milled and polished. When the final shape is obtained, the copper is removed, e.g. by evaporation, without any dimensional change.

With 17% porosity, almost all the pores are found to be interconnecting, so that the porous body can be nearly completely filled with copper. The porosity could be made smaller, and this might be an advantage as regards the use of the porous body as a cathode, since it would reduce the evaporation of barium and barium oxide. However, on further reducing the porosity beyond this value, the machining becomes progressively more difficult because of a rapid increase in the percentage of nonconnecting pores which the copper cannot infiltrate.

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*) Philips Laboratories, Irvington-on-Hudson, N.Y., U.S.A.

[1]) R. Levi, A technique for machining tungsten, Philips tech. Rev. 17, 97-100, 1955/56.

The way in which the cathode is impregnated with aluminate after machining depends upon its shape and size. In general the powdered aluminate is brought directly in contact with the body, and the temperature is raised above the melting point of the aluminate. This is usually carried out in a tungsten or molybdenum furnace, heated by a directly applied current or by induced high-frequency currents. In some cases it is possible to raise the body itself to a sufficiently high temperature by one of these methods of heating. The molten aluminate is then sucked up into the porous tungsten by capillary forces. Excess aluminate can easily be removed from the tungsten surface after cooling. Initially the impregnation process was carried out in vacuo; it was later found advantageous to carry out this operation in hydrogen, since at 1 atm of hydrogen the impregnation time becomes much less critical and the activation time is radically shortened, viz. from about 70 to 3-6 hours in the case of the impregnant containing CaO.

Before the cathode can be used in a tube, the impregnated tungsten body must be attached in an appropriate manner to a holder. Molybdenum is about the best material for the holder: substances that exert a strong reducing action on the aluminate are ruled out, while, moreover, the material must itself evaporate to only a negligible extent at the operating temperatures of the cathode: roughly 1000 °C to 1300 °C. The heater filament which brings the cathode to the desired temperature also has to be accommodated in the holder. The heater filament is made of tungsten and is usually insulated from the holder by means of aluminum oxide.

The method of fitting the tungsten body into the holder depends upon the application. Let us first consider a flat cathode of circular cross-section. In many cases it will suffice if the tungsten disc, which is slightly tapered at the emitting end, is fixed in place in a molybdenum cylinder with an inner supporting ridge by spinning the molybdenum against the tapered part, *fig. 1*. The heater filament can then be pushed into the molybdenum cylinder behind the emitting disc. An advantage of this construction is the good heat transfer from filament to emitting surface.

This method of assembly cannot be used for flat cathodes employed in, say, television picture tubes. In such tubes there may be a potential difference between the heater filament and the cathode part proper, and thus, to ensure that the electrons emitted do not reach the heater filament when the latter is positive with respect to the actual cathode, the two must be completely separated from each other. This would indeed be desirable in any case, since the evaporation of barium or barium oxide towards the heater filament in these tubes may lead to undesirable effects.

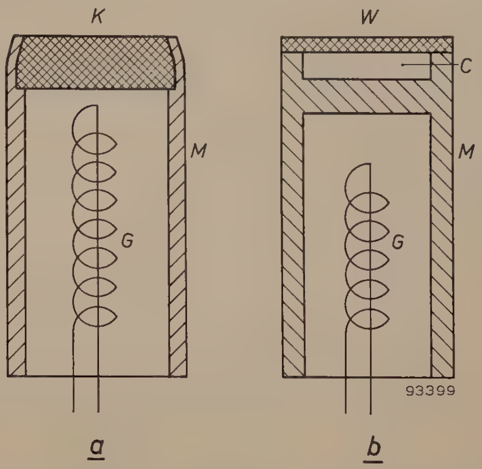

Fig. 1. *a*) A simple way of fitting a flat impregnated cathode (K) in a molybdenum holder. The latter consists of a cylinder (M) with a supporting ridge, in which the cathode disc, i.e. the porous aluminate-impregnated tungsten body, is fixed by bending over the lip of the cylinder. The heater filament (G) is pushed into the cylinder.
b) The L-cathode construction is shown for comparison. The porous tungsten body W forms one wall of the chamber C which contains a reservoir of a suitable barium compound.

Complete separation of filament and cathode is obtained in the following method for preparing the flat cathode.

In addition to the impregnated tungsten disc and the molybdenum cylinder (the latter can be made from a plate which is bent into shape leaving a very narrow seam), a small molybdenum plate is required. This plate is somewhat concave in shape. The three parts are fitted together as shown in *fig. 2* and are then resistance-welded together in one operation. The weld need not meet very exacting demands. It must be mechanically strong, but unlike the weld in the L cathode, it need not be a perfect seal, provided the plate is made a few tenths of a millimetre bigger in diameter than the molybdenum cylinder. The reason is that barium and barium oxide are found to be able to move only a certain distance over the surface of the metal before they again evaporate. At the temperatures employed here, this distance, as work by Rittner and co-workers has shown, amounts to a few tenths of a millimetre for tungsten [2]) and molybdenum [3]). If the smallest distance across the molybdenum is made bigger than this migration distance, then the barium, which migrates over the molybdenum from the sides of the tungsten body, cannot reach the heater filament, even if the weld between the molybdenum disc and the cylinder is not a perfect seal.

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[2]) E. S. Rittner, R. H. Ahlert and W. C. Rutledge, J. appl. Phys. **28**, 156, 1957 (No. 2).
[3]) E. S. Rittner and R. H. Ahlert, submitted for publication in J. appl. Phys.

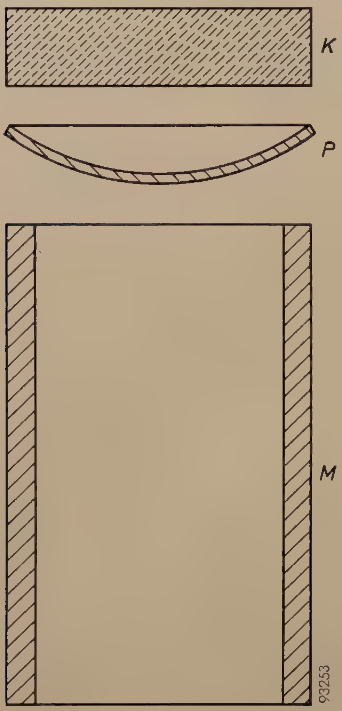

Fig. 2. The construction of a flat impregnated cathode in which the heater filament and the emitting surface are completely separated from each other. The cathode disc K, the molybdenum cylinder M and the molybdenum separating plate P are resistance-welded together in one operation.

If the emitting surface is not flat, but e.g. concave, similar considerations apply. Cathodes of this type are displayed in *fig. 3*.

In cylindrical cathodes the emitting tungsten body is again made first. This is done in the manner already described, i.e. by machining the porous tungsten after it has been impregnated with copper. This body can now be fixed into the holder in several ways, *fig. 4* showing a possible construction. On comparison with the corresponding construction for the L cathode it will be obvious that the impregnated cathode is easier to make, especially for small cathodes, and that more space is available for the heater.

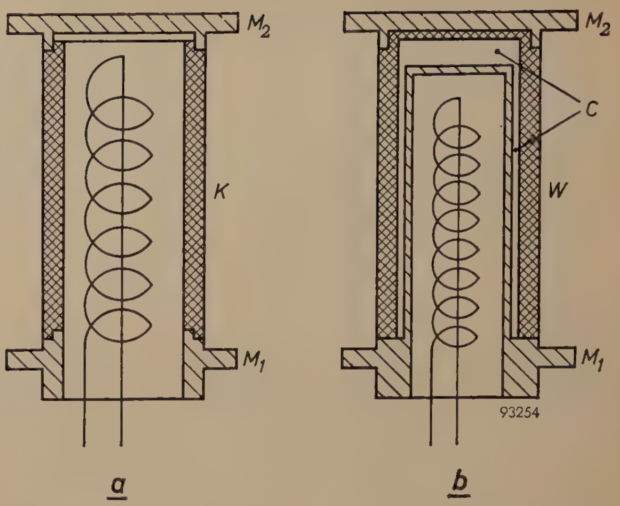

Fig. 4. *a*) Fixing a cylindrical impregnated cathode (K) into a molybdenum holder (M_1, M_2).
b) The corresponding construction of the cylindrical L cathode, shown for comparison. The chamber C is charged with the barium compound.

It was recently discovered that tungsten, sintered to the required high density, can still be machined, e.g. by turning, drilling, etc., after it has been impregnated with the aluminate. Fairly large pieces of cathode material can be made in ingot form which are fashioned later into the desired shape and dimensions. This simplification in cathode manufacture is very attractive as it reduces the number of steps

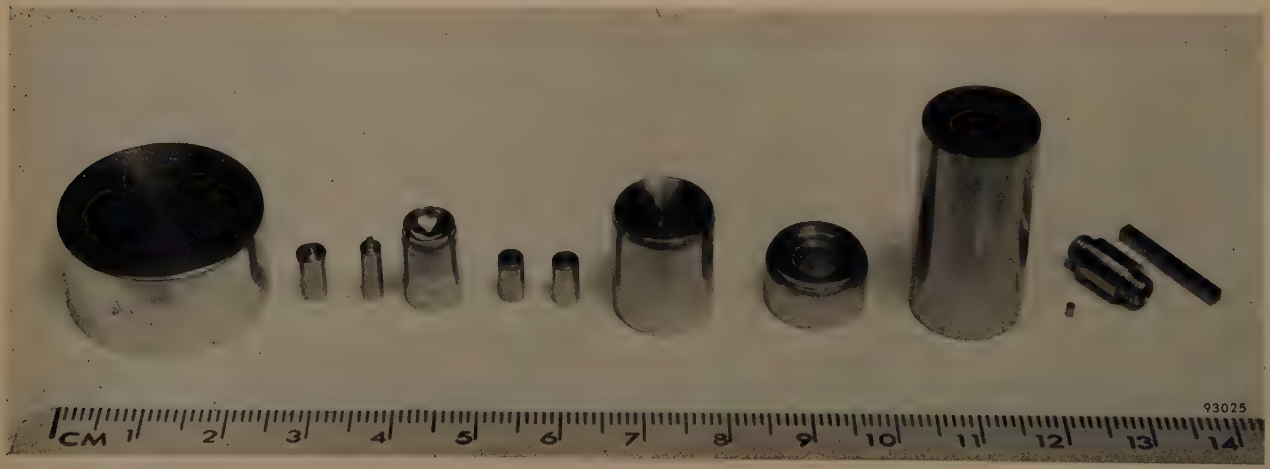

Fig. 3. A number of impregnated cathodes with flat, concave or cylindrical emitting surfaces. It is clearly seen that this type of cathode can be made in many different shapes and sizes.

required and eliminates the need for expensive vacuum equipment. The machining of the ingots impregnated with the aluminates is less easy than when the tungsten is impregnated with copper and therefore this technique cannot be used in the case of the most complicated shapes. In the case of the simplest cathode shapes, such as those of the planar type with a flat emitting area of moderate size, the emissive body can, of course, also be made by compressing the tungsten powder directly into a die, sintering to a porosity of 17% and subsequently impregnating with the aluminates.

The greater latitude allowed in design is the main feature of the impregnated cathode as compared with the pressed cathode. In addition the former exhibits a smaller rate of evaporation.

The emission characteristics

The emission characteristics are studied in a flat diode with a sufficiently small distance between cathode and anode, as described for the pressed cathode (II, page 183). The tube is heated for 1 hour in an oven at 450 °C and a current is then passed through the heater filament, the cathode temperature being gradually raised to 1250 °C. If the cathode is to operate at a higher temperature, the cathode should attain a temperature during this phase which is at least 50 °C higher than the operating temperature.

After the gases released have been pumped off and the pressure in the tube has fallen to its original value, the anode is heated by means of a high-frequency induction current. A direct voltage is then applied between cathode and anode, the cathode being at a temperature of 1250 °C. A current is found to pass which attains a maximum value within a few minutes. The getter is then activated, whereafter the tube can be removed from the pump. Complete activation is then attained within a few hours by heating the cathode at 1225 °C. It is not necessary to apply an anode voltage during this process.

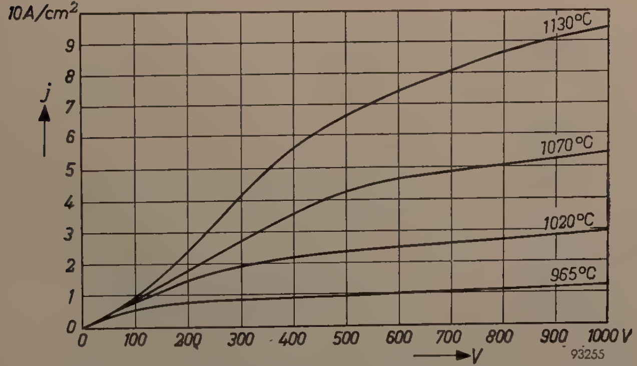

Fig. 5. Current density j of an impregnated cathode measured in a diode as a function of the anode voltage V, for various cathode temperatures.

The emission is measured also in this case by using voltage pulses of about 100 μsec duration. *Fig. 5* shows how the currents so obtained depend upon the voltage applied. The current density is plotted along the ordinate. *Fig. 6* shows that the addition of calcium oxide leads to an appreciable rise in the emission. The values of φ_0 and A in Richardson's equation are calculated from the current density found, yielding in this case $\varphi_0 = 1.67$ V and $A = 2.5$ (A/cm^2) degree^{-2} [4]).

If an activated cathode comes in contact with the air, it loses its emission. It is found however that re-activation carried out as described above, restores the cathode to the same emission as before and the time required for re-activation is no longer than in the first activation. This process can be repeated several times before any effect on the re-activation time and emission current can be detected.

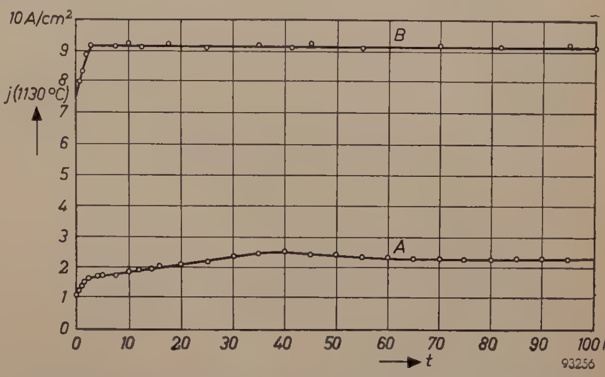

Fig. 6. The improvement in the emission of the impregnated cathode on replacing the barium aluminate (curve A) by barium-calcium aluminate (curve B). The graph shows the rise in current density during activation subsequent to seal-off.

Evaporation and life

In contrast to the situation in the L cathode, the rate of evaporation from the impregnated cathode is strongly time-dependent. Almost all of the total barium evaporates at a rate given by a $t^{-\frac{1}{2}}$ law [5]). While the high initial rate of evaporation can be harmful in certain applications, it has a twofold advantage of providing rapid activation and of overcoming poisoning which is usually most serious during early stages of life. The temperature-dependence of the evaporation follows an $\exp(-Q/kT)$ law within the normal operational range of temperatures; Q is the heat of the reaction producing barium, and may be estimated to be 4 eV per atom.

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[4]) The value of A computed from the figures quoted in I [6]) is 20% higher. Further work of Rittner, Rutledge and Ahlert [5]) has shown that the effective emitting area is 20% greater than the area of the tungsten emitting surface, due to the fact that part of the molybdenum support emits too.

[5]) E. S. Rittner, W. C. Rutledge and R. H. Ahlert, to be published.

If the arrival rate of barium and barium oxide to the surface never falls below the minimum required to keep the surface completely covered with barium, then the life of the cathode is determined by the amount of activating material present in it and by the rate at which barium is lost by evaporation during operation. The life is therefore dependent on the operating temperature and for an impregnated plug 1 mm thick at 1130 °C it amounts to more than 15 000 hours.

Summary of I, II, III. The L cathode developed in the Philips laboratory at Eindhoven several years ago consists of a porous tungsten body, whose emitting surface is covered by a layer of barium and oxygen atoms. The continuous evaporation of barium during operation of the cathode is compensated by the dispensation of barium from a compound located in a chamber behind the porous tungsten body. The L cathode can be operated continuously at very high current densities, its metallic emitting surface is robust and can be made to narrow dimensional tolerances and with good finish; it has a very long life (several thousands of hours), it recovers easily from poisoning and it is highly resistant to bombardment by ions.

The application of the L cathode in tubes, however, is limited by the relatively long time required for degassing and activation, by the difficulties in hermetically sealing the chamber containing the barium dispensing compound and by its limitations in size.

Investigations in the Philips Laboratories at Irvington have led to the development of two new types of dispenser cathodes, working on the same principle as the L cathode (and therefore having the same general electron emission characteristics) but avoiding its drawbacks. The first type is a pressed cathode, made by compacting a mixture (ratio 9 : 1 by weight) of powdered tungsten-molybdenum alloy and barium-calcium aluminate, and heating the pressed mass. The molybdenum content of the alloy (75% by weight) is essential to lower the evaporation rate of barium and barium oxide to the desired level. The second type is an impregnated cathode, made by impregnating a porous tungsten body with molten barium-calcium aluminate. Suitable dispensation of barium is obtained by using tungsten with a porosity of 17% (the porosity is 27% for the tungsten body of the L cathode and 40% for the alloy in the pressed cathode). This porosity value also permits the application of a special technique for machining the tungsten, so that the impregnated cathode can easily be made in a large variety of shapes and sizes, including very small ones.

Both the pressed and the impregnated cathode have much shorter degassing and activation times than the L cathode and can be manufactured more readily. A pressed cathode of flat shape especially lends itself to mass production, but mass manufacture of the impregnated cathode likewise does not involve any great difficulties, while the latter type offers by far the greatest latitude in design. The calcium content of the aluminate in both types of cathodes enhances the electron emission considerably, by a mechanism which is not yet fully understood. These cathodes can also be exposed to the air and reactivated after restoring the vacuum several times during their life. The electron emission of all three types of dispenser cathodes (L cathode, pressed and impregnated cathodes) makes them suitable for use in tubes which call for high current densities, either continuously or in pulses, for several thousand hours.

ELECTRONIC MUSIC

by H. BADINGS *) and J. W. de BRUYN.

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681.84.087.27

*The term "electronic music" is sometimes used when compositions, written for conventional musical instruments, are performed with the aid of electronic devices such as the Hammond organ, the "Ondes Martenot" or electronic music synthesizers **). In recent years, however, the term has come to mean something quite different, being applied to music whose actual composition is based on the use of electronic aids, especially of magnetic recording. These aids can be so employed as to produce entirely new sounds, of which neither the Hammond organ nor any conventional instrument would be capable.*

One of the leading figures in this new field of electronic music is the Dutch composer Henk Badings. His radiophonic opera "Orestes", in which electronic aids play a substantial part, was awarded the Prix Italia in 1954 and has since received more than 200 performances. In his ballet music "Cain and Abel" — which had its first public performance in May 1956 at The Hague — he makes almost exclusive use of electronic aids. Badings' decision to undertake such an experiment evidently owes much to the fact that, having studied engineering at Delft, he has always been keenly interested in technological problems, particularly in those of an acoustical nature.

The fairly extensive range of electronic instruments required to produce "Cain and Abel" was placed at Badings' disposal by Philips Research Laboratories in Eindhoven. It washere that the score was realized jointly by the composer and the co-author of the present article and recorded for performance on magnetic tape. This article gives a description of the electronic aids employed. By way of illustration to the text, a gramophone record giving a selection of the sounds produced is included in this number of the Review. The record also gives a shortened version of the ballet music itself.

In view of the aversion to dogma and the passion for "development" and innovation that characterize Western civilization in our century, no one will be surprised to hear new notes being struck in contemporary music — literally and figuratively. The element of novelty in this connection has two aspects. There is in modern music, just as in modern poetry and art, a perceptible tendency to break with tradition and to shun classical forms of expression and aesthetic laws. On the other hand — and in this respect music might be likened to architecture, with which it has, in fact, frequently been compared — the work of contemporary composers reveals a direct connection with the most conspicuous element of our civilization — technological development. Several composers are at present making use of modern technical equipment in an endeavour to widen the scope of musical expression.

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*) Ir. H. Badings, Bilthoven, Netherlands.

) For the Hammond organ and similar electronic musical instruments, see: A. Douglas, The electronic musical instrument manual, Pitman & Sons, London 1957 (3rd ed.). For music synthesis, see H. F. Olson and H. Belar, Electronic music synthesizer, J. Acoust. Soc. Amer. **27, 595-612, 1955.

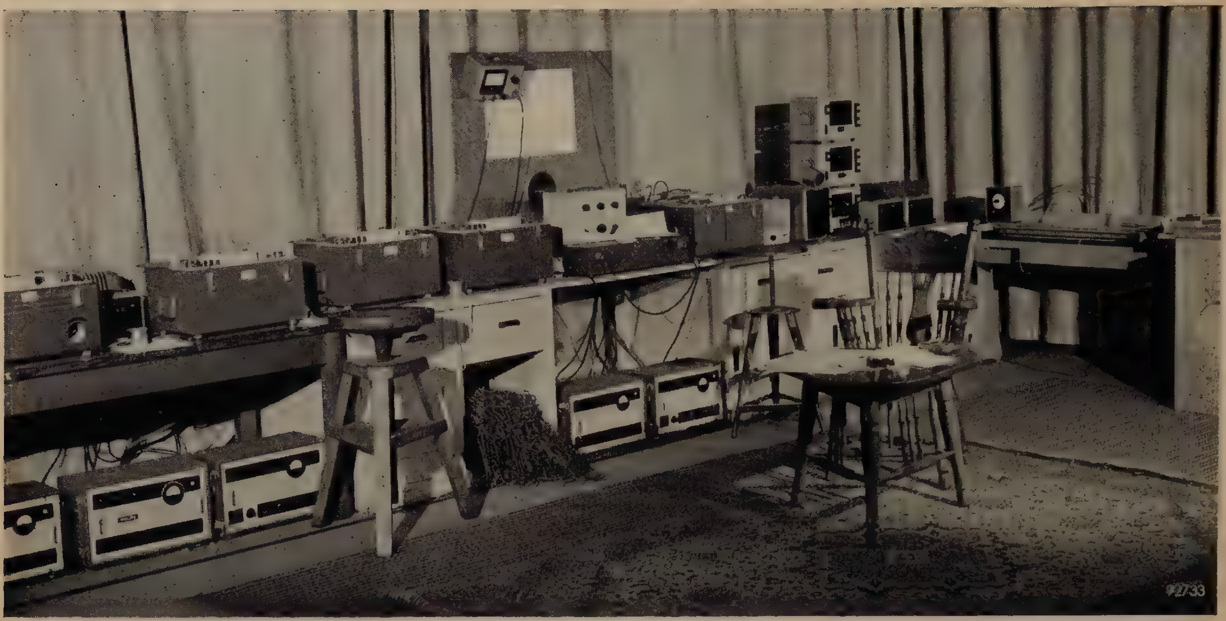

Fig. 1. Part of the equipment employed in the Philips Research Laboratories for making the electronic ballet music "Cain and Abel". On the table are some of the seven magnetic tape recorders used (sometimes five at a time). Also to be seen are a number of amplifiers, a mixing desk, filters, metronomes, various electronic sound-sources, loudspeakers, etc.

This is not the place to go into the evolution of the latter type of music. Those who wish to know more about the subject can find information in various books and published articles ¹). It will be enough to note here that the different trends of composition that can at present be distinguished all agree on one essential point: they invariably employ *electronic* means, and in particular *magnetic recording*, for transforming the sounds and moulding them into something entirely new and unique. All these trends will be referred to by the collective term "Electronic Music" ²). The differences of view between the protagonists of the various trends, some of whom, curiously enough, have brought a new dogma into being, we can only touch upon in passing. Schaeffer in France wants the composer's material to be derived from "concrete" sounds, as for example a steam whistle, a clap of thunder, a dripping gutter, and so on, and he declares all traditional musical conventions taboo ("Musique Concrète"). The "Studio des Kölner Rundfunks", where Eimert and Stockhausen are at work, wants to admit only synthetic sounds produced electronically; this school of thought also seeks to avoid traditional musical elements such as melody, rhythm and harmony, and favours the twelve-note technique introduced by Schönberg in about 1924. Among the composers active in this field in other countries may be mentioned Varèse, Luening and Ussachewsky in the United States, Maderna and Berio in Italy, and in the Netherlands Badings (radiophonic opera "Orestes", Prix Italia 1954; ballet music "Cain and Abel"; film music "The Flying Dutchman") and De Leeuw (radiophonic oratorium "Job", Prix Italia 1956). The less dogmatic attitude of these composers appears from the fact that they sometimes, as in the radiophonic works mentioned, use electronic means in combination with, or only as complementary to, traditional musical instruments.

In this article we shall be chiefly concerned with the technical aspects of Electronic Music. It is evident that the wider the range of electronic resources on which the composer can draw, the richer can be the creative development of this music. For the composition (and "performance") of the ballet music "Cain and Abel", which had its première in 1956, the composer drew on the equipment and cooperation of the Acoustics Group of the Philips Research Laboratories in Eindhoven. The principal apparatus (see *fig. 1*) employed in "Cain and Abel" are described in the following pages.

Examples of the sounds produced are given on the gramophone record appended to this article.

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¹) P. Schaeffer, A la recherche d'une musique concrète, Ed. du Seuil, Paris 1952.
W. Meyer-Eppler, Elektrische Klangerzeugung, Dümmlers Verlag, Bonn 1949.
H. Badings and A. Brandon, Concrete, electronische en radiofonische muziek, Radio Electronica 4, 144-147 and 152, 1956 (No. 3). (In Dutch.)
F. K. Prieberg, Musik des technischen Zeitalters, Atlantis Verlag, Freiburg 1956.

²) The reader should be reminded that the term has been given various other definitions.

The index figures [..] in the text refer to these examples. The reader is recommended to read the article first and then to listen to the record while referring to the condensed explanatory notes given at the end of the article.

Technical aids to Electronic Music

Electronic engineering enters into the creation of Electronic Music in three ways: it provides new sources of sound, it makes it possible to manipulate and transform sounds, and finally it governs the reproduction of the music. For our purposes it will be convenient to begin at the end, that is to discuss the reproduction first.

Reproduction

The term "electronic reproduction" implies the re-creation via amplifiers and loudspeakers of sound originally created at another place or at another time. The appreciation of every type of "reproduction" is primarily determined by the criterion of its fidelity to the original. The familiar shortcomings of electronic reproduction in this respect (noise, distortion and the hole-in-the-wall effect[3])) have been eliminated to such an extent by improvements, for example, in electronic tubes and in recording methods (magnetic recording) and by the introduction of stereophonic techniques, that electronic reproduction can now be made almost indistinguishable from the original. Now that the odium of being a mere substitute need no longer attach to electronic reproduction via loudspeakers, more stress can be laid on the fact that such reproduction offers possibilities which are denied to the original (in this sense it would really be more appropriate to speak of electronic "production" than of "reproduction").

One such possibility resides in the unprecedented freedom with which the position of the sound source or sources can be arranged in a given space. This has been exploited — to give one example — by disposing loudspeakers around an auditorium and by feeding these loudspeakers with electronically delayed music in such a way as to improve the acoustics of the auditorium. This has been done both for "live" music[4]) and for the reproduction of recorded music (stereo reverberation). The composer might go a step further along these lines by not only arranging for different parts of the overall tonal pattern of his score to reach the listeners from different directions and distances — a generalization on the idea of the trumpeter behind the wings in "Fidelio" — but by also giving these parts a different spatial character. It is possible in this way to produce all transitions between the clear and dry directional sound of a trumpet in the open air and the diffuse, non-directional sound of choral music in a church. Something of the kind was in fact done in the performances of "Cain and Abel" at The Hague and Hannover.

Electronic reproduction offers another possibility of the utmost practical importance: in the electronic circuits of the apparatus, the music — or its component sound signals — is available in a form in which its strength (volume) can be controlled by the extremely simple expedient of turning a potentiometer knob. Volume control, and with it the mixing of different parts of a tonal pattern in any desired proportions, is a long-established practice in broadcasting studios. In the early days of broadcasting there was indeed some concern in the artistic world about the power given to the man at the mixing desk to alter the balance of a piece of music. If the mixing engineer has had a good musical training there need be no fear that he will misuse his powers, but from concern about a possible misuse it is only a small step to realize that in the hands of the composer these powers can be turned to useful account. With the volume control he can introduce dynamic figures in notes or combinations of notes where this would otherwise be impossible, as for example in a dying piano chord [1]. By a rapid movement of the volume control, he can deprive a note struck on a percussion instrument of its "attack", and in so doing give a pianoforte passage, for example, a quite unique character [2]. Moreover, there is now no longer a fixed relation between timbre and intensity, as was hitherto the case with many instruments: a whispered passage of a song can be made to sound above an orchestral tutti, although it still retains its "whispered" characteristics.

In the ballet music "Cain and Abel" repeated use is made of a dynamic figure in which the sound intensity is given a bell-shaped variation in time, i.e. it swells rapidly and immediately dies away again. This figure is produced by automatically varying the volume with a device referred to as a tone gate, the circuit of which is given in *fig. 2*; the duration of the bell-shaped variation it produces can be selected in five steps.

The electronic treatment and transformation of sounds

We have seen that in electronic reproduction the sound is at hand in a form in which it can easily be controlled in volume. When the sound is reproduced via the medium of magnetic tape, an even greater measure of control is possible. Originally intended as a means of recording speech and music, for playback as and when required, magnetic tape provides the conductor or composer with remarkable possibilities: they now have the music literally at hand from second to second and can do with it whatever they wish. A good illustration and one that is of considerable practical importance, is the ability to cut out of the tape an unsuccessful passage of a recorded work and to insert in its place a better executed version. In recent years this practice (editing) has brought about a veritable revolution in the gramophone record industry 5). But the composer can also exploit the same procedure in order to create new musical sounds: for instance, with each note of a percussion instrument he can remove the piece of tape on which the attack is recorded, thereby producing an effect which, though of the same nature as that described in the last paragraph, is yet quite different [3]. A very striking transformation is obtained by playing a piece of tape at a speed different from the recording speed [4]. The pitch, of course, changes proportionately, but at the same time an unusual tonal pattern is produced owing to the fact that the relative strength of all harmonics remains exactly the same, which is not generally the case when playing different notes on an instrument. Accelerating the tape also makes it possible to play extremely fast runs with a perfection that is quite beyond the reach of a flesh and blood instrumentalist. Continuously varying the tape speed results in a glissando which, when applied for example to notes played on a pianoforte, produces a most remarkable effect [5]. (This was done by using a tape recorder with a variable frequency power supply for the motor.) The tape can also be played in reverse: the notes of a pianoforte passage then swell up successively, each ending on the "attack" [6]. Another possibility with magnetic recording is to conserve the sound for a very short time on, for example, a rotating magnetic wheel, the sound being taken from the wheel by a number of playback heads and added in variable intensity to the signal being recorded or reproduced (*fig. 3a*). In this way a reverberation [7] is introduced, on the same principle as the method of stereo reverberation employed for improving the acoustics of an auditorium 4)). If the signal taken up by a playback head is fed back to the recording head with a longer delay and greater loop gain (fig. 3*b*), the result is a sound something like the familiar "motorboating" of an oscillator [8].

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[3]) See e.g. R. Vermeulen, A comparison between reproduced and "live" music, Philips tech. Rev. 17, 171-177, 1955/56.

[4]) R. Vermeulen, Stereo reverberation, Philips tech. Rev. 17, 258-266, 1955/56.

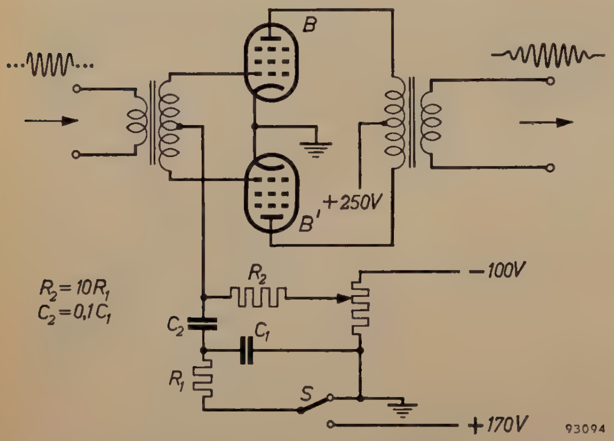

Fig. 2. Basic circuit diagram of the "tone gate". A signal, e.g. an alternating voltage of constant amplitude (constant sound intensity) is applied to the input of a push-pull amplifier with tubes *B* and *B'*. In the position of switch *S* as shown, the tubes are biased below cut-off by a voltage of about —90 V on the grid and no signal appears at the output. When switch *S* is thrown over, the grid bias, rapidly at first, goes more positive and rises above cut-off potential, whereupon (depending upon the charging of capacitors C_1 and C_2) it returns again to —90 V. During that time the amplifier gain rises gradually from zero to a certain value from which it at once gradually returns to zero, so that the input signal arrives at the output with its amplitude modulated in the shape of a bell. The width of this tone pulse (i.e. the duration of the tone or note) can be regulated in five steps by switching over to other values of capacitors C_1 and C_2. After returning the switch to its original position (whereupon the capacitors discharge very rapidly via diodes, not shown) the same process can be repeated.

Magnetic tape is undoubtedly the most important aid to the creation of Electronic Music, not only because of the wide scope it offers for the transformation of sounds, but also because it was with this medium that it first became possible to register individual sounds, to transform them and then to put them together to form a unified whole — in other words, to "compose" them in the musical sense. We shall return presently to this procedure of composition and discuss its consequences from the artistic point of view.

The manipulation of magnetic tape is not the only method of transforming sounds. An obvious method is to use electrical networks, with which variable linear distortions can be effected ("shaping" of the frequency characteristic). A special case in point are *electrical filters* with passbands characterized by sharp or gradual cut-off, beyond which the sound is attenuated or even suppressed [9]. By this means a particular narrow range of frequencies in each note can be given a dominant significance (creation of formants).

Another sound-transforming device which was also used in the production of "Cain and Abel",

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5) See e.g. J. L. Ooms, The recording and production of gramophone records, Philips tech. Rev. **17**, 101-109, 1955/56.

is the *modulator*, in the form familiar for example, in carrier-wave telephony [6]. This modulator has two equivalent pairs of input terminals; if two musical tones are applied to these terminals, both tones appear at the output together with all their combination tones (intermodulation products). Of these the difference tone (beat frequency) is the most prominent. If the one input signal is a musical chord and the other a purely sinusoidal vibration, the chord will appear at the output accompanied by a kind of shadow chord which is a constant frequency lower [10].

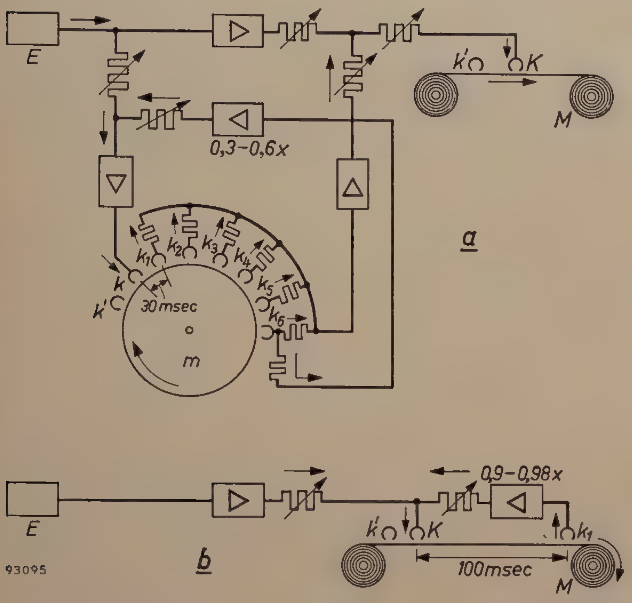

Fig. 3. Arrangements for introducing reverberation (*a*) and excessive feedback (*b*). *E* sound-source (this may be an amplifier if the sound-source is not electronic itself); *M* magnetic tape on which the result of the treatment is registered by recording-head *K*.
a) The signal is also registered by recording-head *k* on a magnetic layer around the rim of a drum *m* with erasing head *k'*; the signal on this layer is then picked up successively by a number of playback heads k_1-k_6, situated at progressively increasing distances from *k*. These signal components, delayed by 30 up to 180 milliseconds, and which are not separately distinguishable but together create the impression of reverberation, are fed, with the original signal, to *K*. In general, reverberation times much longer than 180 milliseconds are needed; to avoid using a very large number of heads for this purpose, the signal picked up by the last playback head k_6 is passed back to recording head *k* (loop gain 0.3 to 0.6×), resulting in six weaker components with delays up to 360 msec, followed by six more even weaker components with delays up to 540 msec, and so on.
b) A feedback loop is formed on the magnetic tape itself between playback head k_1 and recording head *K*, with a delay time of at least 100 msec, and an appreciably larger loop gain (0.9 to 0.98×); in this case the fed-back signal can be heard separately and sounds rather like the "motor-boating" of an oscillator.
With the reverberation equipment in (*a*) one feedback head is not enough, since the overall frequency response is not completely flat and hence the signal cannot be fed back too many times.

Electronic sound-sources

By the manipulation of magnetic tape quite new "sounds" (or rather, vibrations) are produced which can be made audible via a loudspeaker; they are effectively "original" sounds although they were never picked up by a microphone. Once we are familiar with this idea, it soon becomes obvious that we can dispense entirely with the primary sound that can be picked up by a microphone and, instead, apply directly to the loudspeaker such vibrations as can be produced by various electronic devices. A number of electronic sound-sources were used in the composition of "Cain and Abel", some of which have long been known and widely used, although chiefly for other purposes.

In this sense the Hammond organ and kindred instruments are also electronic sound-sources and the composer of "Electronic Music" could, if he wished, use them just as well as conventional musical instruments. When seeking for new tonal possibilities, with the aid (*inter alia*) of sound transformations, there is little point, however, in starting with a rather intricate instrument on which a great deal of effort has already been spent with the object — again by electronic means — of producing or imitating certain timbres of musical sounds. The sound-sources which we have used are therefore of a more elementary and less specialized nature.

From the physical point of view the simplest electronic sound-source conceivable is the *sine-wave generator* (commonly known as an audio signal generator). A loudspeaker connected to such an apparatus delivers an almost purely sinusoidal sound pressure, that is to say a tone practically devoid of harmonics, which strikes the ear as strange and ethereal [11]. The pitch of the tone can be continuously varied by simply turning the frequency control knob. By this method glissandi [12] can be produced at will, but its greatest virtue is that it offers a simple means of obtaining with great accuracy notes with various intervals, i.e. any desired scale. One can therefore deliberately depart from the narrow paths of the conventional equal temperament scale, which divides the octave into twelve equal intervals. In "Cain and Abel" repeated use is made of "pure" (harmonic) intervals, that is to say intervals exactly equal to the whole-numbered frequency ratios of the harmonic series. Although some of these intervals, used melodically, sound somewhat unusual, they are soon accepted by the ear as "good". We mention specially the use of intervals with ratios in which the numbers 7 and 11 appear, which have no counterpart in European music: they have hitherto been rejected since, although they blend perfectly in a chord of harmonically tuned notes, they are strongly dissonant with certain notes in the equal temperament scale (e.g. the seventh). (For this reason a pianoforte is designed so as to suppress as far as possible the "dissonant" seventh harmonic of the fundamental of each string.)

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[6] See e.g. F. A. de Groot and P. J. den Haan, Modulators for carrier-telephony, Philips tech. Rev. 7, 83-91, 1942.

To achieve harmonic tuning — as, indeed, for many other purposes of checking — we made use of a cathode-ray oscilloscope. A harmonic interval produces on the oscilloscope screen a typical stationary Lissajous figure. This method does away with all the intonation difficulties that arise if an instrumentalist is asked to play, by ear, unusual intervals with the traditional continuously tunable sound-sources (the singing-voice, violin, etc.).

Fig. 4. The composer playing a multivibrator.

The counterpart of the sine-wave generator is another familiar electronic device, which is widely used, for example, in counter circuits — the *multivibrator*. This produces a sound which contains all harmonics of the fundamental up to the audio limit, the successive harmonics differing in intensity according to some slowly varying function. (The resulting signal, which may have a square or a sawtooth waveform, can also, of course, be modified by passing it through an electrical filter or shaper circuit.) Two versions of this sound-source were used in the composition of "Cain and Abel". The first, which has been given the name "baritone clavier", supplies a signal having an almost square waveform, the fundamental of which can be adjusted in pitch to a series of discrete frequencies by means of push-buttons [13]. With the second instrument the pitch of the fundamental can be varied continuously (making glissandi possible); in the low register the vibration approaches a square waveform, but in the high register it gradually assumes a sawtooth form [14].

A photograph and the circuit diagram of this multivibrator can be seen in *fig. 4* and *5*.

For various parts of "Cain and Abel" use was also made of a *noise generator*. As a sound-source this device differs from all other known sources in that the sound it produces has a continuous instead of a line spectrum. Noise having a constant energy distribution over the entire spectrum of audible frequencies ("white noise") is musically not particularly interesting since there is nothing that can be varied except its intensity; nevertheless, with the aid of filters, it is possible to impose on the noise a somewhat vague impression of pitch. To do this we employed filters passing a frequency band of one or several octaves [15], or a third [16], these bands being capable of displacement in certain fixed steps.

In the electronic sound-sources mentioned above, the frequencies of the vibrations, with all their components, are determined by *electrical* elements. In another, rather hydrid, group of electronic sound-sources the frequencies (pitch and tone colour) are determined by *mechanical* means, although the vibrations only become acoustically effective through the medium of a loudspeaker. To this group belong two kinds of "electronic drums" and an "electronic clavichord", which were used for "Cain and Abel". The first drum was essentially just a large condenser microphone, the vibrations

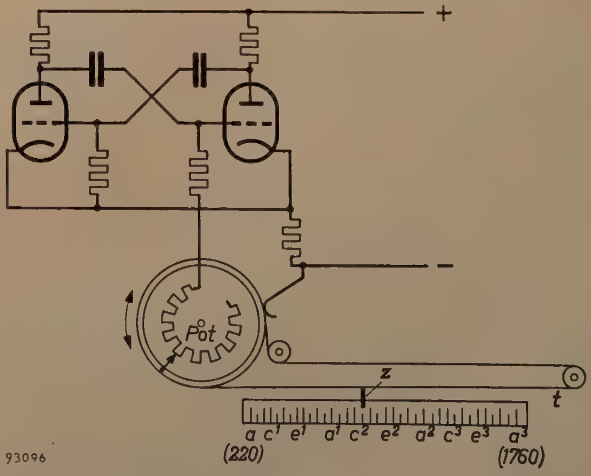

Fig. 5. Circuit diagram of a multivibrator with continuously variable pitch. The pitch is controlled by a potentiometer *Pot* whose sliding arm is fixed to a wheel; a cord and pulley system enables the musician to turn the wheel by moving a clip *z* along a scale calibrated in notes from *a* to a^3. By moving *z* rapidly to and fro a natural vibrato can be produced.

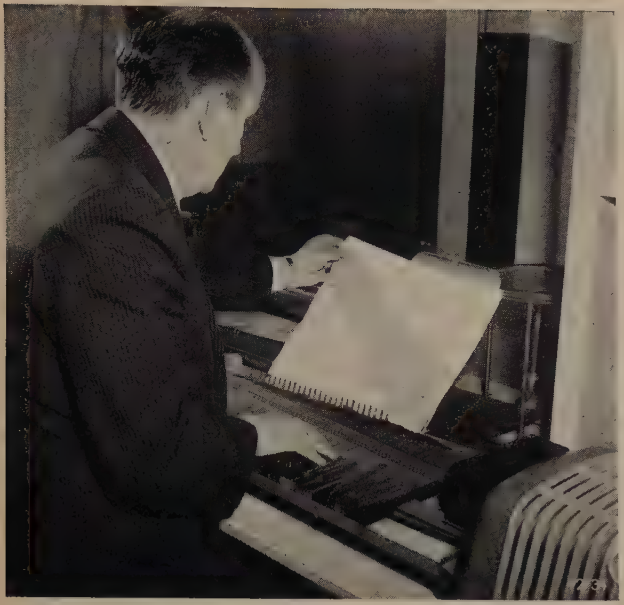

Fig. 6. The electronic clavichord.

being produced by taps or drum rolls on the diaphragm. The second consisted of a steel sheet whose vibrations were picked up at a specific position by a piezo-crystal; according to the part struck and the manner of damping the vibrations, a considerable variety of sounds could be produced [17]. A photograph of the "electronic clavichord" [18] is shown in *fig. 6* and a description of the device is given in the caption to *fig. 7*, which shows the circuit diagram.

The last to be mentioned of our range of electronic sound-sources is a particularly remarkable instrument which we call an *optical siren* [7]). In this device the pitch is determined mechanically, namely by the speed of a motor-driven disc, but the tone colour is produced by optical means, a pattern cut out in a sheet of paper being successively scanned by slits in the revolving disc placed in a beam of light, and the light-variations so produced being converted into electrical variations by a photo-electric cell (*fig. 8*). "Tone-colour melodies" created with this instrument are to be heard in several parts of "Cain and Abel" [19].

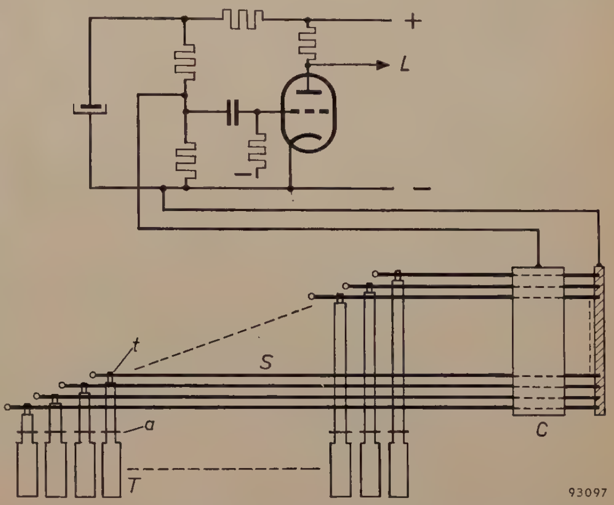

Fig. 7. Schematic representation of the electronic clavichord. The parallel single wires *S* of this instrument are made to vibrate in the same way as in a normal clavichord, i.e. with key-operated tangents (*t*; *T* are the keys and *a* their pivots) which, after being struck, also act as the endpoints of the respective strings. The strings as a whole constitute one electrode of a capacitor, the stiff plate *C* above the strings being the other electrode. This capacitor is incorporated in an amplifier circuit in exactly the same way as a condenser microphone. A loudspeaker can be connected either directly to the amplifier at *L*, or via various electronic devices.

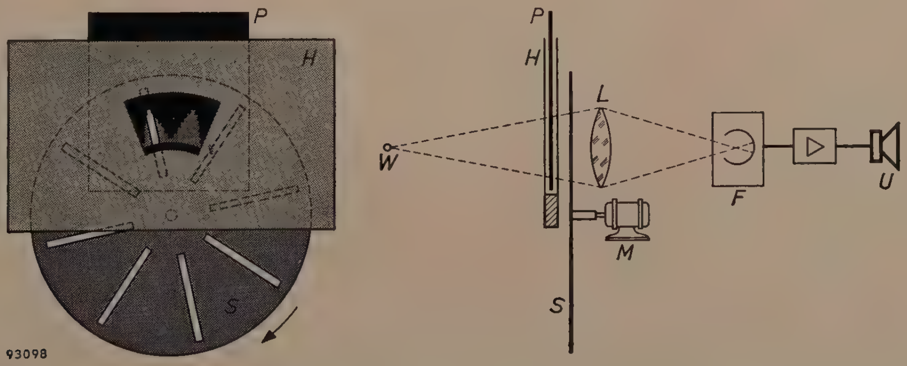

Fig. 8. Schematic representation of the optical siren (see photo on title page). A beam of light emitted by light-source *W* is concentrated on a photomultiplier tube *F* by a lens *L*. Situated in the beam is a holder *H* containing a sheet of paper *P* in which a waveform has been cut out, and behind which rotates a disc *S* driven by a motor *M*. As the disc rotates the pattern is successively scanned by narrow radial slits in the disc, and the light passing through the slit varies in accordance with the ordinate of the pattern. The photoelectric current in *F* varies in the same rhythm and is passed via an amplifier to the loudspeaker *U*.

A natural vibrato effect can be introduced by holding the sheet of paper in the hand instead of fixing it in the holder.

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[7]) J. F. Schouten, Synthetic sound, Philips tech. Rev. 4, 167-173, 1939.

The composing and "performance" of electronic music

Outwardly the most striking difference between an "electronic" and a traditional composition is that the former cannot be performed by musicians in the presence of the public. The process of transforming sounds, for example by cutting and splicing, retarding, accelerating or reversing magnetic tape, excludes this possibility at once and leads to quite a different procedure. The composite sounds which the composer indicates at a given moment in his score — for example, a melody from the signal generator, an accompanying pianoforte figure, on which is to be superimposed rhythmical figures from the clavichord with accenting by an electronic drum — are each produced separately by a musically trained engineer and transformed on instructions given by the composer. The result is a number of "acoustic layers" (in this instance four), each recorded on a separate magnetic tape [20]. Tuning control by means of fixed frequencies, and accurate time measurement ensure that the acoustic layers are properly matched and synchronized (in the composition of "Cain and Abel" the tuning was checked with the aid, among other things, of a set of electrically driven tuning forks which produce tones from c^1 to c^2). The layers are then put together in the correct dynamic relationship either all at once or, if preferred, one by one [21], until at last a single magnetic tape is obtained on which the entire work is recorded. This tape is now ready to be played to the public.

A frequently heard misconception is that this procedure must lead to a rigid, mechanical tonal pattern in which there is no room left for artistic interpretation. It cannot be denied that direct contact between performer and audience is lost owing to the prior performance of the work and its reproduction via magnetic tape, although the same applies to broadcast music and to music played on gramophone records. It is also true that, in the case of "Cain and Abel", for example, the work was largely performed for the first time by the composer himself — partly because there are as yet so few musicians who can "play" electronic apparatus, and partly because the act of composing in this new realm of music sometimes runs parallel with the act of performance [8]). Nevertheless, there is certainly room for interpretative re-creation, as testified by the fact alone that the composers of Electronic Music do not identify their work with a magnetic tape but set down the musical thought they wish to express in the notation of a score (*fig. 9*), even though, in doing so, they must necessarily use many new signs, often inventing them themselves. The scope for interpretative re-creation appears in the fact that in making as well as in putting together the acoustic layers indicated in the score there are innumerable details, for example the question of relative sound intensities, that must be decided by musical feeling. This has already been made plain by the results of making versions of the radiophonic opera "Orestes" in other languages: the individual performances (in Dutch, German and English) reveal very striking differences of interpretation in the electronic sounds, although in none of them were the composer's intentions misrepresented.

The composer of Electronic Music need scarcely offer a justification of his work. From the psychological point of view he can regard his experiments in this unexplored territory as sharing in that passion for innovation and development which, as we remarked at the beginning, is characteristic of Western civilization. He can supply their musical motive by pointing to the charm or the fascination of the new sounds, and in particular:

the timbres with their rich variations;
the harmonic tuning;
the wide scope in the dynamics of the music;
the tempi and the brilliance of the figures, not subject to human limitations;
complete freedom to combine independent rhythms (whereby the metrical accents on the average can even cancel each other out, producing a curious, hovering movement [22]).

Having, therefore, regard to the common definition of music — as the art of conveying artistic emotions from man to man by the medium of air vibrations — there can never be any doubt in the mind of the composer of electronic music about the right of his brain-child to exist, but he must leave the decision to the listener — of today or perhaps of tomorrow.

Explanatory notes to the acoustical illustrations

Side 1 of the gramophone record appended to this article contains examples of individual sounds touched upon in the text; each example is introduced by a *morse-code signal*, by which it can be identified in these explanatory notes. The index figures [..] refer back to the text. Side 2 contains a much abridged version of the ballet music "Cain and Abel"; it was put

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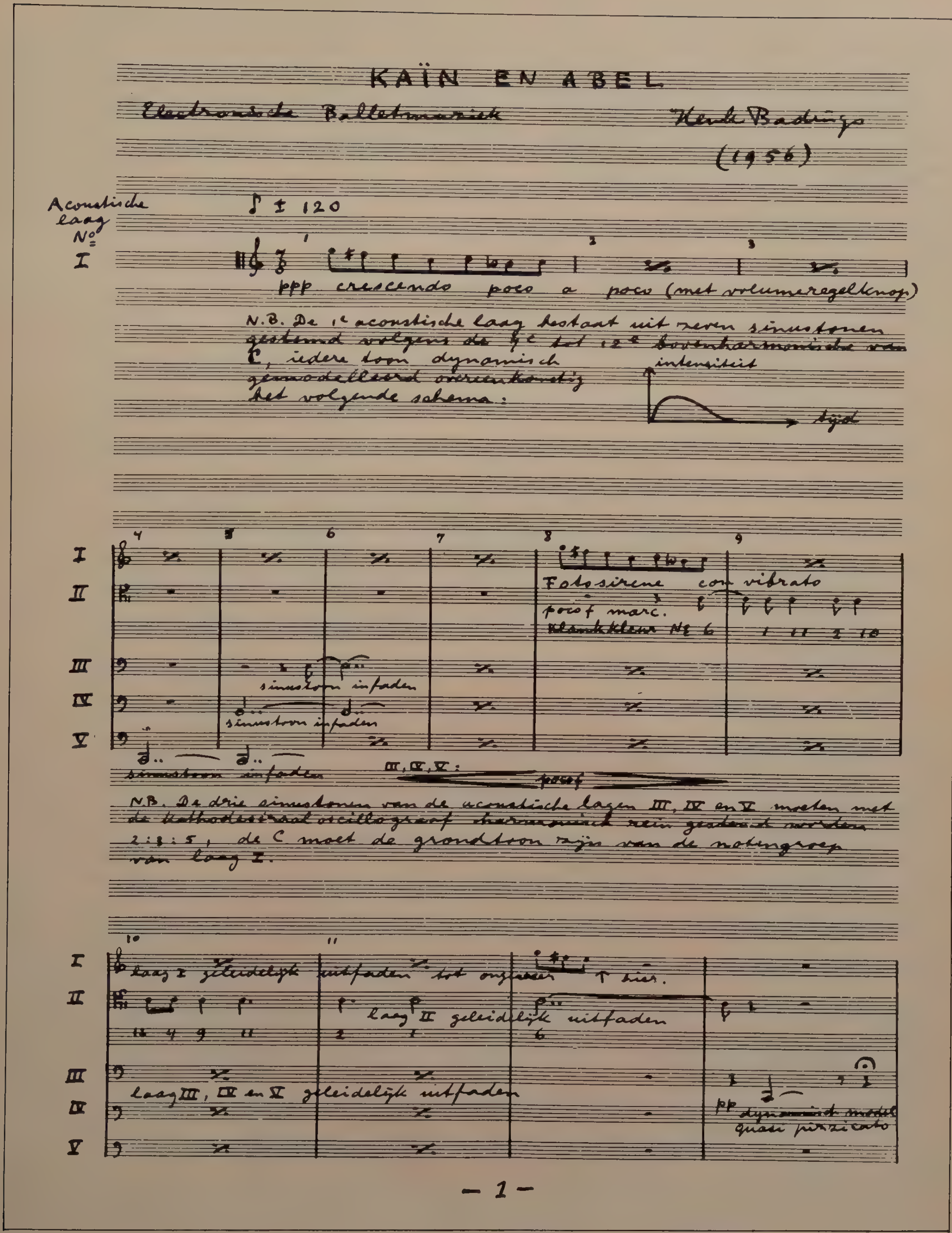
[8]) As a matter of interest, the process of composing and making the magnetic tape for "Cain and Abel" was completed within one month. In general, however, the realization of an electronic score is a rather time-consuming process, and roughly speaking requires just as many "man hours" as it does to rehearse with an orchestra a traditional concert piece of comparable length and complexity.


KAÏN EN ABEL
Electronische Balletmuziek
Henk Badings
(1956)
Acoustische laag No I
♪ ± 120
ppp crescendo poco a poco (met volumeregelknop)
N.B. De 1e acoustische laag bestaat uit zeven sinustonen gestemd volgens de 6e tot 12e boventharmonische van C, iedere toon dynamisch gemodelleerd overeenkomstig het volgende schema:
intensiteit
tijd
I
II
III
IV
V
Fotosirene con vibrato
poco f marc.
Klankkleur No 6
sinustoon infaden
III, IV, V:
poco f
N.B. De drie sinustonen van de acoustische lagen III, IV en V moeten met de kathodestraal oscillograaf harmonisch rein gestemd worden 2:3:5, de C moet de grondtoon zijn van de notengroep van laag I.
laag I geleidelijk uitfaden tot onzichtbaar
hier.
laag II geleidelijk uitfaden
laag III, IV en V geleidelijk uitfaden
pp dynamisch model quasi pizzicato
— 1 —

92797

Fig. 9. Page 1 of the score of the electronic ballet music "Cain and Abel". It can be seen that five "acoustic layers" are used and that the composer of this kind of music is at present obliged to add a lot of written explanation to his score in order to specify his intentions. For the optical siren ("Fotosirene" in the score) twelve vibration patterns (each producing different tone colours — "klankkleur" in the score) were cut out beforehand and numbered, so that it was only necessary to indicate in the score the numbers and the pitch (r.p.m. of the disc).

In other parts of the score other methods of notation are used, including a kind of tablature (a finger-position notation as formerly used for the lute) and a graph in which the required vibration frequencies are directly plotted as a function of time.

together by the composer from the original tape (playing time about 20 minutes) so as to offer in a playing time of 8 minutes a large number of striking passages without doing too much violence to the musical form of the whole.

The examples on side 1 fall into three groups:

I. Illustration of the effect of electronic sound treatments, each applied to the same traditional musical sound, viz. a pianoforte figure, recorded on magnetic tape.

II. Illustration of the sound of several of the electronic sound-sources discussed in the text; some are the original sounds direct from the source, others are treated as under I.

III. Demonstration of the combining of acoustic layers. A passage from "Cain and Abel" is chosen which occurs on side 2 of the record; to make the demonstraton clear, however, the layers are put together anew and some treatments prescribed in the score (including the addition of reverberation) are omitted.

Group I (Various electronic treatments)

First the pianoforte figure itself is heard, consisting of a chord, a run, and the same chord an octave higher.
Then:

—• Tape retarded (speed halved) [4].
Acceleration (tape speed doubled and tape played twice) [4].
Acceleration (tape speed quadrupled and tape played three times) [4].
Glissando of the chord over one complete octave [5].

—•• Dynamic figure introduced in chord by varying the volume control [1].
Attack of each note in the run suppressed by means of the volume control [2].
Attack of the same notes removed by cutting out the pieces of tape at which each attack occurs [3].

—•• • Reversal of time by playing the tape in reverse [6].

—•• •• Excessive feedback applied to the chord (played twice) [8].
Reverberation added to complete piano figure [7].

Group II (Various electronic sound-sources)

——• Sine-wave generator: staccato notes [11],
glissando [12],
legato notes [11].

——•• Optical siren: "tone-colour melody" [19].

——•• • Multivibrator ("baritone clavier") [13].

——•• •• Multivibrator (continuously variable) [14].

——•• •• • Steel sheet, beaten and damped in different ways [17], also in part electronically treated by the introduction of dynamic figures and by accelerated playback (cf. passage near the end of side 2).

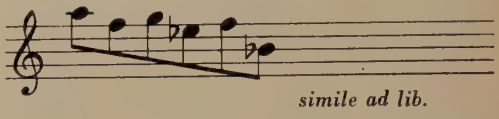
——•• •• •• Noise generator:
Bandwidth 1 octave (successively 8-4, 4-2, 2-1 and 1-0.5 kc/s) [15].
Bandwidth 1 third (mean pitch varying in steps from 100 to 1600 c/s) [16].

——•• •• •• • Electronic clavichord [18]:
The same figure as the pianoforte figure in Group I.
A different figure; magnetic tape played with continuously increasing speed.
Intermodulation of the last figure and a sinusoidal tone of rising frequency.

Group III (Combination of acoustic layers)

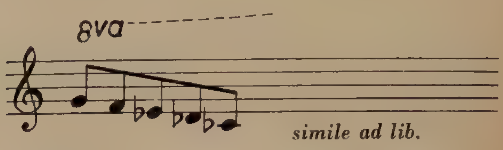
— A complete passage, composed of five layers.

—• First layer:



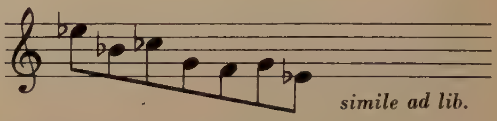
obtained from pianoforte figure played at 224 quavers per minute (♪ = 224); tape played at double speed in reverse [20].

—•• Second layer:



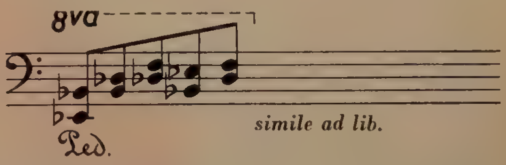
obtained from pianoforte figure produced by depressing the keys of the chord on the keyboard and scraping a hard object over the strings involved, ♪ = 200; tape played at double speed.

—•• • Third layer:



obtained from pianoforte figure played at ♪ = 65; tape played at double speed.

—•• •• Fourth layer:



pianoforte figure played at ♪ = 105; normal tape speed.

—•• •• • Fifth layer: sound consisting of notes struck on tubes, similar to the chime of a bell in E flat, followed by the clavichord figure [18] with intermodulation given at the end of Group II, but with tape speed increasing still further.

——• Combination of third and fourth layers [21] [22].

——•• Combination of third, fourth and first layers.

——•• • Combination of third, fourth, first and second layers.

———• All five layers combined, same as heard at the beginning of this group.

Summary. In contemporary music various trends of composition have evolved which may be described under the general heading of "Electronic Music". A characteristic common to them all is the use of magnetic recording and other electronic aids for the treatment and transformation of sounds into something entirely new. The composers "raw material" may be produced by traditional musical instruments, or derived from "natural" sources or created by electronic means. In this article the electronic instruments are described which the composer, Henk Badings, used in the Philips Research Laboratories, Eindhoven, for creating his electronic ballet music "Cain and Abel". The authors deal in some detail with a number of possible treatments, such as retarding, accelerating and

reversing, making dynamic figures, filtering, intermodulating, producing feedback effects and adding reverberation. They then go on to describe some electronic sound-sources, including the sine-wave generator, multivibrators, noise generators, the "optical siren" and an electronic clavichord. The composer sees the musical significance of using such devices in the wide scope they offer, e.g. for adding innumerable new timbres to traditional musical instruments, for working freely with scales differing from the conventional equal temperament scale, for producing faster and more brilliant figures than would otherwise be humanly possible and for employing extremely complicated rhythms that could scarcely be maintained by even the most skilful ensemble.

The various possibilities are illustrated by acoustic examples given on a gramophone record appended to this article, and which also offers an abridged version of "Cain and Abel".

Philips Technical Review

Acoustic illustrations to the article:

Electronic Music

by **H. Badings** and **J. W. de Bruyn,**

Philips tech. Rev. 19 (1957/58), No. 6

AN OPEN-AIR LABORATORY FOR ROAD LIGHTING

628.971.6.006.2

At the new Philips factory at Turnhout (Belgium), which manufactures sodium and mercury-vapour lamps, there is an open-air lighting laboratory, now in use for more than six months. As can be seen from *fig. 1*, the open-air laboratory consists essentially of a broad road (320 m long and 14 m wide) provided with ten lighting masts mounted on trolleys. The arms of these masts, on which the fittings are mounted, can be adjusted in height by means of electrical hoist mechanisms contained in the trolleys. The adjusted height can be read on a dial; the maximum height is 12.5 m above the ground, and the minimum height, for the convenience of changing the fittings, is 1 m (see *fig. 2*).

The laboratory serves a fourfold purpose, being employed for fundamental research in the field of road lighting, for judging the performance of new fittings and lamps, for providing assistance in the design of road-lighting installations and for demonstrations.

Fundamental problems, such as the nuisance of glare on lighted roads and the question of what uniformity of surface luminance (brightness) is required for good visibility, can only be partially studied on scale models. At a certain stage a test under actual conditions will be necessary, and that is where the open-air laboratory proves its value.

The open-air laboratory provides the facilities for checking the behaviour of new designs of lamps

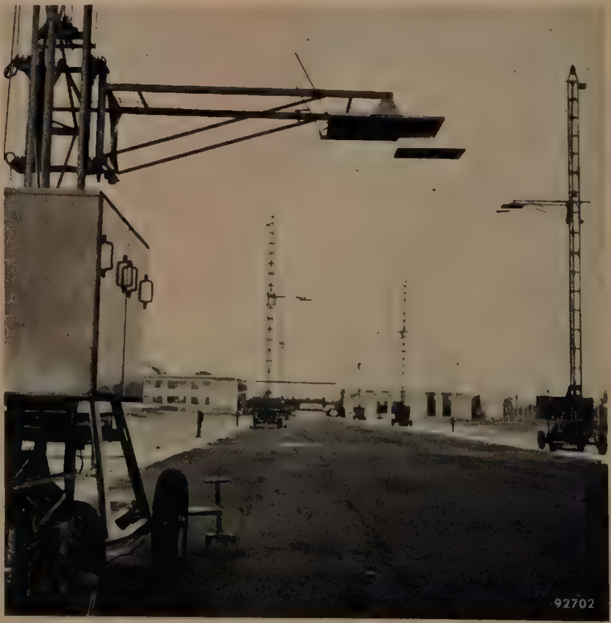


Fig. 1. Daylight view of the Philips open-air laboratory for road lighting.

and fittings against the expectations of photometric observations indoors. This in turn offers a firmer and more reliable basis for making decisions on putting a new product into production.

In the design of road lighting layouts it has been found that calculations alone are not enough to provide a complete picture of the merits of a given installation. If this applies to a situation where the road surface is dry, it is all the more applicable to wet road conditions, which must inevitably be taken into consideration. When it is a question, not of standard layouts for streets or roads of no special character, but of lighting important arterial roads or places where the traffic situation is complicated, it is then particularly desirable to be able to test the efficiency of a proposed installation under conditions which closely approach those which will obtain in practice. For this reason the introduction of a major lighting system is often preceded by a trial layout along a short stretch of the actual road; in some cases several such stretches may be fitted out with trial installations having different types of lamps and fittings. This is a costly procedure and clearly not very efficient; it offers no opportunity of making modifications at short notice in, for example, the positions of the lighting poles or in the height of the fittings, in order thus to arrive experimentally at the best solution of the problem. In the open-air laboratory, however, all the necessary facilities are ready to hand.

The open-air laboratory is eminently suitable for demonstrating to interested parties the advantages and disadvantages of different lighting installations. In such comparative demonstrations it must be possible to alter rapidly the spacing and height of the light-sources and also to change the lamps and fittings smoothly and promptly whenever necessary. Having regard to the fact that many of the gas-discharge lamps used for street-lighting need a relatively long time to come up to operating temperature, each trolley contains a large light-tight compartment in which fittings, with lamps already burning, are mounted ready for use on sliding racks (*fig. 3*). A single example will serve to illustrate the scope for demonstrations offered by the many facilities of the open-air laboratory. A trial installation was recently set up along a certain section of a large new motor-road in the Netherlands. After completion, this installation was found to fall far short of expectations. When our Lighting Laboratory was consulted on the matter, a demonstration was arranged at the open-air laboratory where, in the space of two hours, four lighting systems were shown (including that already tested and rejected).

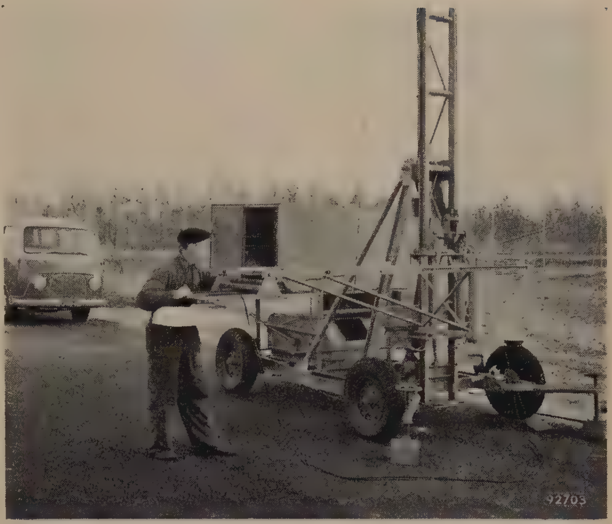


Fig. 2. Changing a fitting in one of the masts. The arm is brought down to its lowest position on the mast. The fitting is mounted on a frame which is slid on to the arm. The frames also fit in the slots at the sides of a compartment in the trolley; the compartment is made light-tight by a sliding panel (see also fig. 3). A van equipped with measuring instruments can be seen on the left (see also fig. 5).

We shall now touch briefly on some details of the equipment of the open-air laboratory and on the measurements that can be carried out there.

The experimental road has a dark (asphalt) surface for 200 metres of its length, the remaining 120 metres having a light surface (a porphyry granite gravel). A general visual impression can thus be obtained of the effect of a lighting system on both dark and light road surfaces. Luminance measurements (which are of course of the utmost importance for appraising a given

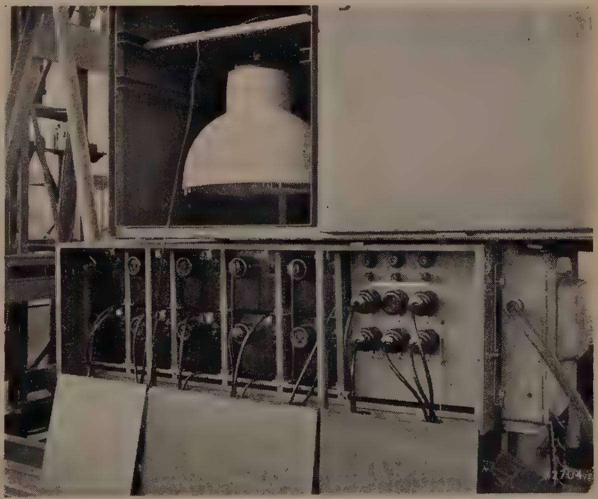


Fig. 3. A fitting mounted on its frame in the light-tight compartment on the trolley, where several fittings with lamps already burning can be stored. When changing a fitting, then, no time is lost waiting for the lamp to come up to temperature. Below the compartment can be seen the various ballasts needed for the lamps.

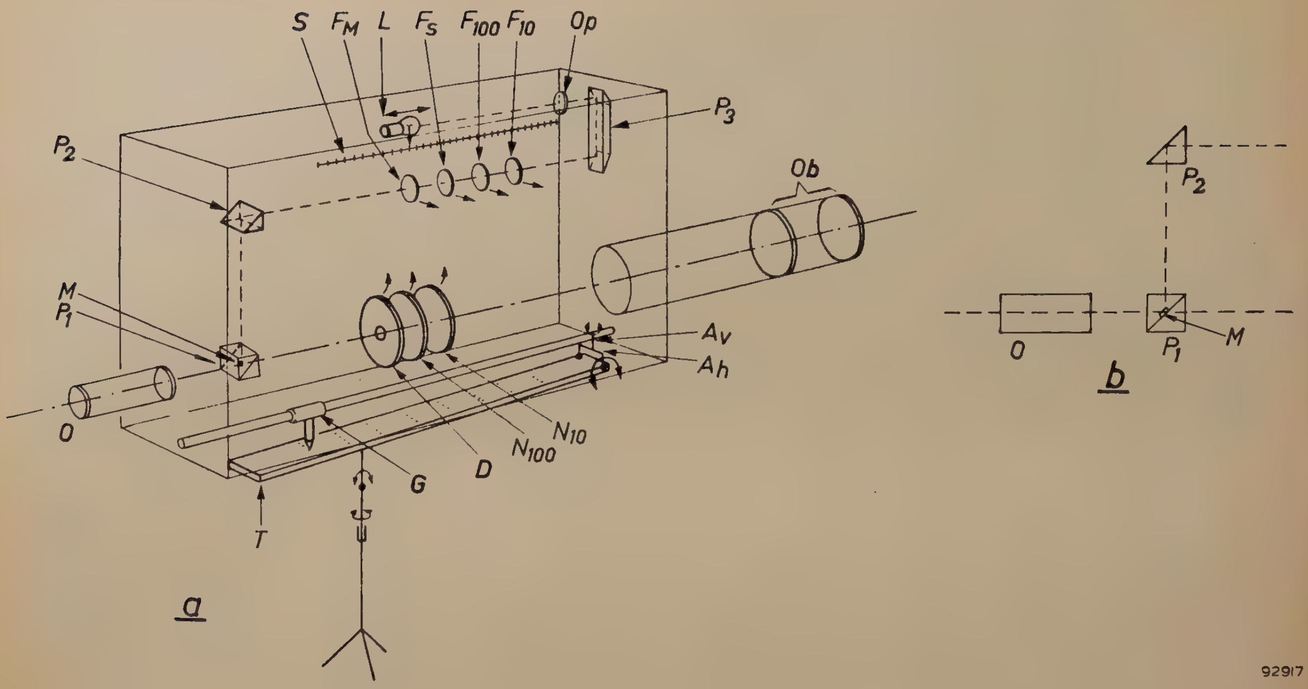


Fig. 4. *a*) Schematic representation of the visual luminance meter developed for road-lighting measurements. The objective *Ob* projects an image of the part of the road under investigation on to the mirror *M* (vapour-deposited on one of the prisms of P_1 — see detail in (*b*) — before these parts are cemented together). Through the eyepiece *O*, the image of the road can be sharply observed together with the mirror itself. The brightness of the comparison field from *M* can be adjusted until it is equal to that of the part of the road appearing immediately above the upper edge of *M*. This is done by varying the distance of the lamp *L* from the frosted-glass disc *Op* (to be read from a scale *S*). Via prisms P_2 and P_3 the brightness of *Op* is observed in *M*. The attenuation filters F_{10} and F_{100} can be interposed in the path of light in order to reduce the brightness observed in *M* by a factor of 10, 100 or 1000, thereby shifting the measuring range to lower luminances. Filters F_S and F_M serve for adapting the colour of the comparison field to a road lit by sodium or mercury-vapour lamps. With filters N_{10} and N_{100} the measuring range can be shifted to higher luminances. *D* is a diaphragm. The total measuring range is from 0.01 to 10^6 cd/m^2. A particular feature of the meter is its very small comparison field (the dimensions of *M* are 0.2×0.6 mm), which enables specific parts of the road to be measured even from a considerable distance. Another feature is the facility for accurately adjusting the optical axis of the meter with respect to the road. The meter can be turned about a horizontal axis A_h and a vertical axis A_v with respect to a hardened steel plate *T* fixed to the stand. By a certain procedure employing datum lamps placed on the road, a specific fixed position with respect to the road can be given. A sleeve *G*, which can be slid along a rod fixed to the meter, has a pin attached to it which rests on plate *T*. If *G* is pushed forward, the meter tilts slightly forward about A_h. The point of the road on which the meter is directed is entirely determined by the position of the pin of *G* on *T*. By calibration marks on the plate *T* it is possible to sight the meter on the point of the road where the luminance is to be measured. For this purpose *T* is illuminated, and an optical device with cross-wires is fitted to *G* for reading off the scale.

situation) are not, however, confined to the two types of surface mentioned, samples of several other road surfaces being mounted on low trolleys which can be moved to any position and hence included in the measurements. To make the tests less dependent upon the weather, water-sprinklers are situated at intervals of 20 m down the middle of the road.

The measurements and observations now being carried out in the open-air laboratory concern, apart from the luminance, the intensity of illumination on the road surfaces, the glare caused by direct light from the fittings and the visibility of objects on the road. The situations investigated, in addition to being measured photometrically, are recorded photographically as faithfully as possible.

Some of the instruments and apparatus used are contained in a specially equipped van, which also serves for carrying out measurements on existing road-lighting installations. The instruments employed for measuring the luminance and its distribution on the road surface are of two types: visual (subjective) instruments and instruments permitting objective measurements. One of the most useful instruments is a luminance meter developed specially for road-surface measurements by the Eindhoven Lighting Laboratory. With this type of meter the luminance, seen from a fixed point where the meter is set up, is measured as a function of direction. Particularly on sections of the road surface far removed from the meter, a slight change in direction corresponds to a large displacement over the road surface. Consequently, one of the requirements imposed on the meter is that the direction of its optical axis should be capable of being adjusted and read off with great accuracy: for the azimuth setting the accuracy must be a few minutes of an arc, and even greater accuracy is required for adjusting the angle of inclination in the vertical plane. A schematic representation of the luminance meter is given in *fig. 4;* the optical principles of the meter and the measures adopted to ensure accurate adjustment are briefly described in the caption [1]). These measures are only effective, however, provided the meter is set up on firm ground. For this reason the meter on its stand can be let through a hatch in the floor of the van directly on to the road (*fig. 5*); this arrangement has the added advantage that instrument and observer are protected from wind and weather by the shelter of the van.

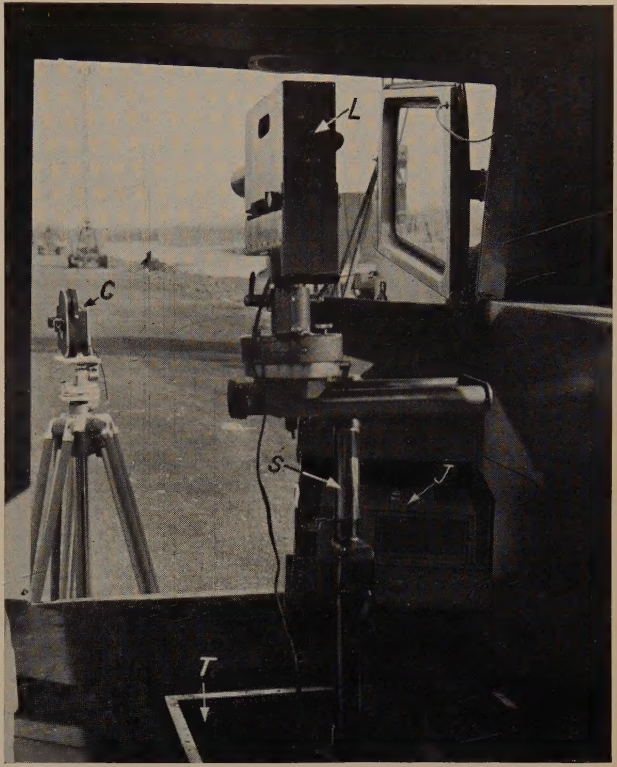


Fig. 5. Interior view (towards the rear) of the van (see also fig. 2) equipped with measuring instruments. The luminance meter L is mounted on a stand S, which is let down to the road through a hatch T in the floor of the van. J is a luxmeter, C a cine camera.

The data obtained from the tests performed in the open-air laboratory provide a welcome supplement to the knowledge gathered by experiment and experience over the years, and can play a great part in ensuring that the development of public lighting technique keeps pace with the rapid increase in the density of traffic on the roads.

I. HAMMING and
J. F. T. van HEEMSKERCK VEECKENS.

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[1]) For a fuller description see J. B. de Boer, Lichttechnik **7**, 273-275 and 307-309, 1955, or Revue générale des Routes et des Aérodromes **25**, 83-90, 1955.

ABSTRACTS OF RECENT SCIENTIFIC PUBLICATIONS BY THE STAFF OF N.V. PHILIPS' GLOEILAMPENFABRIEKEN

Reprints of these papers not marked with an asterisk * can be obtained free of charge upon application to the Philips Research Laboratory, Eindhoven, Netherlands.

2470: M. J. Sparnaay: Zur Deutung der Hückel-Krafftschen Zusatzglieder in der Debye-Hückelschen Theorie der starken Elektrolyte (Z. phys. Chem. (Frankfurt a. M.) **10**, 156-160, 1957, No. 3-4). (On the explanation of the Hückel-Krafft extra terms in the Debye-Hückel theory of strong electrolytes; in German.)

In the classical theory of electrolyte solutions a quantity K^{-1} was introduced, having the dimension of length and usually interpreted as the mean distance between positive and negative ions constituting the solution. One of the assumptions of the theory was that the ions were considered as point charges. A modified theory which assumes that the ions are hydrated, and therefore occupy a certain volume, results in the quantity K^{-1} being replaced by K^{*-1} where, approximately,

$$K^{*-1} = K^{-1} \{1 + 2Bn(1-g)\}.$$

B is the volume of the hydrated ion, n is the number of ions per cm^3 of the solution and g is a factor containing the electric charges of the ions. The purpose of the present paper is to present a simple theory for the understanding of g instead of the very complicated theory used hitherto. It is found that, generally, $g < 1$.

2471: M. J. Sparnaay: Non-equilibrium diffuse double-layer (Trans. Faraday Soc. **53**, 306-314, 1957, No. 3).

The diffuse part of the double layer in an electrolyte solution near an electrode is described by the Poisson-Boltzmann distribution. This distribution will undergo perturbation if an electric current is applied. Then the ions in the double layer will transport electricity. Two idealized cases of this non-equilibrium state of the diffuse part of the double layer are calculated. The case of an alternating current is also treated. It appears that deviations from the equilibrium distribution are nearly always small in practical cases.

2472: D. Hofman, J. A. Lely and J. Volger: The dielectric constant of SiC (Physica **23**, 236, 1957, No. 3).

Letter giving results of dielectric-constant measurements of very pure SiC crystals at 20 °K and 77 °K and at frequencies between 1 kc/s and 100 kc/s. It is concluded that $\varepsilon = 10.2 \pm 0.2$.

2473: P. C. van der Willigen and L. F. Defize: Das Lichtbogenschweissen von Stahl mit CO_2 als Schutzgas (Schweissen und Schneiden **9**, 50-59, 1957, No. 2). (Arc welding of steel with CO_2 as shielding gas; in German.)

See these abstracts No. **2394**.

2474: A. van Weel: Implications of phase precompensation in a television transmitter on the shape of the radiated signal (J. Brit. Instn. Rad. Engrs. **17**, 129-134, 1957, No. 2).

The smears after black-to-white transitions due to phase errors in the receiver can be compensated by an overshoot introduced by a phase-precompensating network in the video-frequency section of the transmitter. In a negative-modulation system this overshoot can only be accommodated in the available modulation space by raising the maximum-white level from 10 per cent to at least 20 per cent, which is equivalent to a loss of transmitted signal power of 30 per cent. Curvature of the modulation characteristic makes a complete compensation impossible. With a positive-modulation system, the output stage of the transmitter should be capable of delivering pulses, reaching to 22 per cent over and above the maximum-white level.

2475: R. Dijkstra and J. de Jonge: The ortho/para distribution of methylol groups in the reaction of phenol and formaldehyde II (Rec. Trav. chim. Pays-Bas **76**, 92-100, 1957, No. 1).

A potentiometric method is described for the quantitative determination of o-methylol phenol. The method is based on the acidic properties of the complex formed by o-methylol phenol and boric acid. In the reaction of phenol and formaldehyde, leading to the formation of mono-methylol compounds, 57-61% ortho substitution takes places. The distribution of the methylol groups over the ortho and para places of the phenolic nucleus was determined with the aid of the potentiometric method mentioned above.

2476: H. A. Klasens, A. H. Hoekstra and A. P. M. Cox: Ultraviolet fluorescence of some ternary silicates activated with lead (J. Electrochem. Soc. **104**, 93-100, 1957, No. 2).

The fluorescence and phase diagrams of the following Pb-activated ternary systems were investigated: SrO-MgO-SiO_2; SrO-ZnO-SiO_2; BaO-MgO-SiO_2; BaO-ZnO-SiO_2. Eleven new ternary silicates were identified, some of which proved to be very good base materials for Pb-activated phosphors with peak emissions ranging from 3000 to 4000 Å.

2477: H. Bremmer: Theoretische beschouwingen betreffende de atmosferische verstrooiing van radiogolven (T. Ned. Radiogenootschap **22**, 87-106, 1957, No. 2). (Theoretical considerations on the atmospheric scattering of radio waves; in Dutch.)

Theories of scatter propagation are dealt with. The importance of the Fourier spectrum connected with the spatial distribution of the local deviations of the dielectric constant is discussed. The influence of the assumed spatial auto-correlation function of these deviations is also put forward. Various consequences of the theory, such as fading and coherence properties, are briefly mentioned.

2478: J. A. Kok and M. M. G. Corbey: Testing the electric strength of liquid dielectric or insulating material (Appl. sci. Res. **B 6**, 285-295, 1957, No. 4).

Starting from the assumption that electric breakdown of liquid hydrocarbons takes place in general far below the intrinsic breakdown strength owing to irremovable and filterable contaminants migrating towards a place of maximum electric stress, where a conducting bridge may be formed, the authors attempt to combine the theory they propose with earlier experimental results. Hydrocarbon oil of rather poor quality was purified by means of an electrostatic Cottrell-filter. This filter removed most of the foreign particles of high dielectric constant, by which the one-hour breakdown strength was increased from about 10 kV/mm to 60 kV/mm.

2479: J. H. Uhlenbroek, M. J. Koopmans and H. O. Huisman: Investigations on agricultural fungicides, I. Trichloromethyl thiolsulphonates (Rec. Trav. chim. Pays-Bas **76**, 129-146, 1957, No. 2).

The preparation and the biological properties of a number of strongly fungitoxic compounds of the general type RSO_2SCCl_3 (trichloromethyl thiolsulphonates) are described in this paper. The phytotoxic character of these compounds may be lowered considerably by suitable substitution in the group R.

2480: J. F. Carrière: Bijzondere elektronenbuizen voor sommige impulstechnieken (Ned. T. Natuurk. **23**, 97-115, 1957, No. 4). (Special electron tubes for use in certain pulse applications; in Dutch.)

Properties and limitations of various types of electron tubes for counting purposes. Among the tubes dealt with are gas-filled tubes, vacuum tubes, tubes making use of secondary emission, cathode-ray tubes (beam-switching tubes) and the trochotron (or magnetron-type) beam-switching tube.

2481: J. P. L. Bots: Resorption of cholecalciferol from an intramuscular oil depot (Rec. Trav. chim. Pays-Bas **76**, 209-212, 1957, No. 3).

By injecting chickens intramuscularly with radioactive cholecalciferol (vitamin D_3) in oil and determinating the radioactivity still present after various times, it is shown that an intramuscular depot of vitamin D_3 is only slowly absorbed in the course of at least seven months.

A 1: A. Rabenau: Perowskit- und Fluoritphasen in den Systemen ZrO_2-$LaO_{1.5}$-MgO und ZrO_2-$LaO_{1.5}$-CaO (Z. anorg. allgem. Chemie **288**, 221-234, 1956, No. 3-4). (Perovskite and fluorite phases in the systems ZrO_2-$LaO_{1.5}$-MgO and ZrO_2-$LaO_{1.5}$-CaO; in German.)

In the system ZrO_2-$LaO_{1.5}$-MgO a ternary compound has been found having the composition $La(Zr_{0.5}Mg_{0.5})O_3$. This compound has a perovskite structure and a narrow range of homogeneity. A compound with the same composition and structure was found in the CaO system: $La(Zr_{0.5}Ca_{0.5})O_3$. Here it forms a complete range of mixed crystals with $CaZrO_3$. The occurrence of cubic fluorite phases in the ternary systems has been investigated. The fluorite phases of ZrO_2 with the oxides MgO and CaO are not miscible with the ZrO_2-$LaO_{1.5}$ fluorite phase. On the other hand the latter with a composition of $ZrO_2 : LaO_{1.5} = 1 : 1$ ($La_2Zr_2O_7$) can take up to about 50 mol% of MgO. This behaviour is explained by the fact that with this composition a special structure occurs, as is shown by the occurrence of superstructure lines. A compound of the pyrochlore type is probably involved.

R 319: B. van der Veen: On the angle between wave front and displacement of plane acoustic waves in quartz (Philips Res. Rep. **12**, 273-280, 1957, No. 4).

Piezoelectric vibrating X-cut bars of quartz are generally made rectangular. Following a suggestion of C. Franx it is shown that in general a non-rectangular shape can give zero coupling to unwanted transversal vibrations. In this case it is necessary to compute the angle between the wave front and the displacement of plane acoustic waves in quartz.

R 320: J. Bloem and F. A. Kröger: Interstitial diffusion of copper in PbS single crystals (Philips Res. Rep. **12**, 281-302, 1957, No. 4).

At temperatures $100 < T < 500$ °C, Cu can diffuse rapidly into PbS via interstitial sites. Existing cation vacancies are filled by copper, while copper may also be bound by sulphur at internal surfaces (cracks, dislocations). The diffusion co-efficient follows the relation $D_{\text{Cu}} = 5.10^{-3} \exp(-7130/RT)$ $\text{cm}^2 \text{ sec}^{-1}$. Interstitial copper gives rise to donor levels lying ~ 0.02 eV below the conduction band, and thus causes *n*-type conductivity. In the presence of sulphur in the atmosphere (H_2S) copper does not enter the crystal; interstitial copper already present in the crystal may be drawn out when the crystal is heated in such an atmosphere. The effect is attributed to a lowering of the thermodynamic potential of copper by the formation of Cu_2S or CuS.

R 321: J. Bloem and F. A. Kröger: Interstitial diffusion of nickel in PbS single crystals (Philips Res. Rep. **12**, 303-308, 1957, No. 4).

Under reducing conditions, nickel may penetrate into PbS crystals at temperatures $T < 500$ °C at which the self-diffusion in PbS is negligible; it diminishes *p*-type conductivity and may cause *n*-type conductivity with donors of a depth $E \sim 0.03$ eV. The diffusion probably takes place via the interlattice with a diffusion constant $D_{\mathrm{Ni}} = 17.8 \exp(-22000/RT)\ \mathrm{cm^2 sec^{-1}}$. Under sulphurizing conditions (H_2S) the nickel can be drawn out of the crystal again and the original conductivity restored.

R 322: C. Z. van Doorn: Anisotropy of colour centres in alkali halides (Philips Res. Rep. **12**, 309-323, 1957, No. 4).

Additively coloured crystals of KCl and NaCl, which have been irradiated in the F-band at room temperature, show, in addition to the F-band, absorption bands which are due to M- and R-centres. Irradiation in these bands with polarized light at 77 °K produces an unpolarized infrared emission due to F-centres and two infrared emission bands, due to M- and R-centres, showing polarization. The degree and directional properties of this polarization depend on the type of centre and method of excitation. Irradiation with polarized light in the F-band also induces dichroism in the F- and M-bands. Models for the centres are discussed which may explain these phenomena.

R 323: M. T. Vlaardingerbroek, K. S. Knol and P. A. H. Hart: Measurements of noisy fourpoles at microwave frequencies (Philips Res. Rep. **12**, 324-332, 1957, No. 4).

A new method of measuring the characteristic noise quantities of noisy linear fourpoles is described. Applied to microwave frequencies this method is very simple when the fourpole is matched to the characteristic impedance of the waveguide, which can always be achieved. The method is applied to a microwave triode amplifier.

R 324: J. L. Meijering: Residual entropy of ice, and related combinatorial problems (Philips Res. Rep. **12**, 333-350, 1957, No. 4).

The theoretical residual entropy of disordered ice is about 5% higher than Pauling's value $R \ln (3/2)$. For the corresponding quadratic lattice the difference is 6%. Here a persistency effect is found, which in $Ag_2H_3IO_6$ must give rise to unequal a-priori probabilities of the dipole orientations. The entropy computed for the graphite-type honey-comb lattice is 20% higher than that found by Lipscomb. This difference is related to a boundary effect. It is shown that Chang's expression for the entropy of diatomic molecules in a lattice can be derived directly with Pauling's method.

R 325: J. H. N. van Vucht: Some data about the system cerium-thorium (Philips Res. Rep. **12**, 351-354, 1957, No. 4).

Metallographic and X-ray diffraction experiments show a complete mutual solubility of cerium and thorium in the face-centred cubic phase. The lattice parameters deviate markedly from Vegard's law in the negative sense.

R 326: K. F. Niessen: Influence of foreign ions on the critical field strength of an antiferromagnetic (Philips Res. Rep. **12**, 355-363, 1957, No. 4).

The critical field strength is calculated for an anti-ferromagnetic in each of whose sublattices a number of original magnetic ions has been replaced by foreign magnetic ions with different magnetic moments or simply by non-magnetic ions. Especially in the latter case the change in the critical field strength can be given by a simple formula.

R 327: L. J. van der Pauw: Analysis of the photoconductance in silicon (Philips Res. Rep. **12**, 364-376, 1957, No. 4).

A general formula is derived for the change in voltage drop across a semiconductor sample, caused by illumination. It is shown that this formula is a convenient starting point for analysing photoconductive experiments. In particular it is shown that in relevant cases white light may be used without difficulty. The analysis of the low-frequency phase shift between the voltage drop and the light signal as a function of the thickness of the sample yields the values of the bulk lifetime, the surface-recombination velocity and the drift mobility of the minority charge carriers. Also the properties of traps can be determined. Finally the results of some measurements at room temperature are discussed.